ontario hydro
research division
COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

EXECUTIVE SUMMARY

Darlington G.S. 'A' EPS and EPG Ventilation System Analysis - Tornado Qualification

JOHN W.R. JACKSON

Mechanical Testing And Development Section
Mechanical Research Department

Using the TVENT1-P computer code, from Los Alamos, for the analysis of tornado generated gas-dynamic transients in the flow networks formed by the ventilation systems of the EPS and EPG buildings, it was found that the tornado induced pressure and flow pulses were sufficiently large to affect the structural and performance integrity of the ventilation system ducting and fans and to warrant the use of tornado dampers. Other solutions such as bypassing the fans or adding louvre resistance to attenuate the pulses were investigated but are not recommended.

job	file	date	report no.
24-284-40053	824.24	November 17, 1988	88-181-K

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

ontario hydro
research division

TO Mr.M.A. Machacek
Manager of Engineering - Darlington G.S.
Projects and Construction

Darlington G.S. 'A' EPS and EPG Ventilation System Analysis - Tornado Qualification

Using the TVENT1-P computer code, from Los Alamos, for the analysis of tornado generated gas-dynamic transients in the flow networks formed by the ventilation systems of the EPS and EPG buildings, it was found that the tornado induced pressure and flow pulses were sufficiently large to affect the structural and performance integrity of the ventilation system ducting and fans and to warrant the use of tornado dampers. Other solutions such as bypassing the fans or adding louvre resistance to attenuate the pulses were investigated but are not recommended.

At your request a project was initiated to assess the capabilities of the EPS and EPG building ventilation systems to withstand the pressure and flow pulses induced by a Design Basis Tornado. A previous report, "Tornado and Rail Line Blast Protection for Darlington G.S. 'A' EPS and EPG Buildings - Progress Report", B88-13-K , outlined the preliminary work done to assess the state of the art in analysis of tornado and blast effects on ventilation systems. This report contains the tornado transient analysis and solutions drawn therefrom.

INTRODUCTION

This analysis shows the pressure and flow pulses that occur within the ducts and across the fan units when a tornado passes over and/or by the EPS and EPG buildings. The major pressure pulse is a negative one as shown in Figure 1 caused by the cyclonic air circulation forming the funnel of a tornado. Its duration is the result of the translational speed (96 km/h) of the tornado and its core diameter (92 m). This negative pressure can cause the implosion of ducting, and can affect the fans by overspeeding the exhaust fan and stalling the inlet fan. The secondary pressure pulse is the positive one, Figure 2, caused by the stagnation of the circulating winds in the event that the core of the funnel comes in close proximity to a target louvre.

The TVENT1-P computer code used in the analysis was developed at the Los Alamos National Laboratories specifically for the analysis of tornado transients, and has been verified at their laboratories on full scale mock-ups. The code allows one to model ventilation systems of enormous complexity and to apply almost any pressure transient to the boundary nodes, as long as the transient does not "shock up" as a blast wave would. The code produces pressure and flow profiles and can also produce differential pressure plots to indicate flow reversal problems such as could be the case in inter-zone cross contamination in nuclear plants during high winds. The code will also handle material transport.

VENTILATION SYSTEM MODELLING

Figures 3 through 8 show the EPS and EPG buildings at Darlington site along with details of the ventilation openings and their orientation. It should be noted that the EPS exhaust and inlet louvres are very close to one another so that a tornado would present itself to the two openings simultaneously, whereas in the case of the EPG building, the translational velocity of the tornado would cause a slight delay between depressurizations at the two ports.

Internally, the EPS building ventilation system can be represented schematically as in Figures 9 and 10. The two representations refer to the summer and winter settings of the system, with and without bypass. The maximum probability for tornados in this area is from April to October according to Environment Canada so there could very well be a circumstance wherein the winter configuration would see the pulse. The EPG building is similarily shown in Figures 11 and 12.

For entry into TVENT1-P, the node and branch relationships must be entered along with the performance curves of the fans. The performance curves along with the detailed building layouts and the system schematics were obtained from the Mechanical Department of Darlington Project. The system is then balanced to the design flows, in this case to within 2% for the fans and major ducts and within 10% for the low flow branches. Balancing is performed with atmospheric pressure at the boundary nodes, for example the inlet and exhaust louvres.

A simulation is performed by applying a pressure profile(s) to whatever boundary node(s) necessary. The program then iterates through the code to satisfy the convergence criteria and outputs the pressure profile for each node, the flow profile for each branch, and a good deal of other information on differential pressures and particulate transport if requested.

The code has not only been verified in full scale tests, but also provides feedback from those tests by properly handling cases wherein the standard fan curves must be extended into the second and fourth quadrants to account for backflow and outrunning flow respectively.

TORNADO APPROACH SCENARIOS

Figures 13 and 14 show the various combinations of boundary conditions considered.
The tornado core could come from any direction so the worst case directions were chosen and modelled. The EPS building is faily insensitive to this since the inlet and exhaust are close together. The pressure drop would occur simultaneously at both the inlet and exhaust.
For the EPG building on the other hand, traversal from inlet to exhaust at the tornado translational velocity of 96 km/h takes 0.468 seconds. As a consequence, runs were performed with the pressure dropping at the exhaust 0.468 seconds before it began to drop at the inlet, and vice versa.
Similarily, if the tornado approaches at a right angle to the line connecting inlet and exhaust, the pulse will strike both simultaneously.
The effect of the winds rotating around the core also had to be taken into effect, with the pulse being chosen as the peak positive stagnation pressure due to winds of 320 km/h and decaying in 1.7 sec, again related to the translational velocity of the tornado. The only ducts to be affected by such a pulse would be the EPG building inlet and the EPS building exhaust since these are the only fully exposed surfaces upon which the wind could stagnate and still have that pressure transmitted inside.
It is important to try all of these scenarios because of the complexity of pulse interactions within the ducting system with pressure reinforcements as well as attenuations taking place.
In the case of the EPG building, a single run was conducted with the tornado pulse applied at the battery room louvre alone as if the other boundary nodes had been protected with tornado dampers. This was to ascertain whether or not the battery room needed protection.

PROCEDURE

The investigation consisted of applying the various approach scenarios to the various ventilation configurations.
The sequence of trial simulations was as follows:

1. EPS - SUMMER vs WINTER CONFIGURATION - tornado at all ports simultaneously
2. EPG - SUMMER vs WINTER CONFIGURATION - tornado at all ports simultaneously
3. EPS - SUMMER vs WINTER CONFIGURATION - wind loading
4. EPG - SUMMER vs WINTER CONFIGURATION - wind loading
5. EPG - SUMMER vs WINTER CONFIGURATION - tornado passing from inlet to exhaust
6. EPG - SUMMER vs WINTER CONFIGURATION - tornado passing from exhaust to inlet
7. EPG - SUMMER CONFIGURATION - tornado at battery room louvre alone

The remaining simulations constituted an attempt to find solutions by modelling various louvre resistances to assess their attenuation of the pulses and to see their effect on steady state performance, and by short-circuiting flow around the fans to the fan room to model blowout panels designed to attenuate the pulse by redirection into a capacitive node.

8. EPG - LOUVRE ATTENUATION - pulse attenuation vs steady state flow blockage
9. EPG BLOWOUT PANEL - pulse attenuation by redirection and damping.

RESULTS

1. EPS - SUMMER vs WINTER CONFIGURATION - tornado at all ports simultaneously
Figures 15 to 21 show the nodal and branch breakdown of the EPS building in its summer ventilation configuration. These pressures and flows are easily matched to the nodes and branches of the schematic in figure 9. Figures 22 and 23 show the same effect in the condensed fashion that will be adopted for the rest of the data. This condensed format presents all of the pertinent data, but only the important peaks are readily discernable for comparison from one simulation to the next. The lesser peaks are of no interest in this study, but do form trends that can be extracted.
Figures 24 and 25 show the EPS building in its winter ventilation configuration. As can be seen, the winter peaks are not as severe as in the summer, for pressure as well as flow, in the case where the tornado is assumed to traverse the building such that the inlet and exhaust ports are subjected to the same pulse at the same time.

2. EPG - SUMMER vs WINTER CONFIGURATION - tornado at all ports simultaneously
The same trend holds true for the two configurations of the EPG building when the inlet and exhaust are loaded simultaneously, figures 26 to 29.

3. EPS - SUMMER vs WINTER CONFIGURATION - wind loading
Figure 30 shows that the winter configuration downline pulse is slightly higher, but well within acceptable bounds.

4. EPG - SUMMER vs WINTER CONFIGURATION - wind loading
Figure 31 shows that the EPG building shows the opposite effect to that observed in 3. above.

5. EPG - SUMMER vs WINTER CONFIGURATION - tornado passing from inlet to exhaust
Figures 32 to 35 show the summer configuration pressures for this scenario to be quite a bit more severe than those in the winter configuration.

6. EPG - SUMMER vs WINTER CONFIGURATION - tornado passing from exhaust to inlet
Figures 36 to 39 show the same results as 5 above, although analysis of data shows that the inlet to exhaust excursion is slightly more severe than the exhaust to inlet excursion.

7. EPG - SUMMER CONFIGURATION - tornado at battery room louvre alone
Figures 40 and 41 show the results of assuming all other ports into the EPG building have been protected, and the tornado pulse occurs only at the batteryroom louvre. The resultant pulse, restricted only to the room, is within bounds at any rate.

The results of running TVENT1-P show that the pressures in the internal nodes as well as the external nodes to be very high in magnitude. Such high negative pressures have the capability of collapsing the ducting causing possible widespread blockage of air flow. Pressures are at the level that tests would have to be performed on all of the affected ducts in order to be sure of their effect on the ducts.

In many cases, the flows resulting from the tornado pulse reached values that would warrant full scale tests on the fan units to fully assure one not only that the overspeed would not destroy the fan on high outflow, but also that the fan could successfully restart through the stall on excessive backflow.
In the case of the positive pressure from the stagnation of the wind against the louvre, the internal pressures and flows are virtually unaffected because of capacitance in the external plenums. The pressure spike in the Figure 2 represents an unattainable envelope since the input pressure is based on full stagnation. In reality, the input pressure would be much lower since the louvres are 50% open and full stagnation pressure could not be reached beyond the louvres because of flow losses, louvre angle, etc. In any event the effects are seen only in the plenum structures before the pulse enters the ducting. In a similar fashion the associated figures show the flow disturbances to be minimal even for an exagerated pulse.

The test on the battery room alone shows there to be enough capacitance in that room to attenuate the pulse in the internal nodes to the point of insignificance.

TRIAL SOLUTIONS

Attempts were made to simulate solutions to the excessive pressures and flows. Two of the most hopeful from the standpoint of simplicity were to attenuate the internal pulses by adding resistance to the peripheral louvres and to save the internal ducts and the fans by bypassing the pulse into the fan room capacitance via blowout panels.

8. EPG - LOUVRE ATTENUATION - pulse attenuation vs steady state flow blockage
Figure 42 shows a more detailed model of the EPG system modelling the boundary louvres.
The added resistance did in fact attenuate the pulses but cut the steady state flows down drastically. Such a solution would exact an enormous run-time cost penalty over the life of the station, not to mention the cost of altering the fan to provide design flows. Figure 43 shows a moderate amount of damping from an order of magnitude increase in the resistance coefficient of the louvre, but the steady state flow is reduced by 50%.

9. EPG BLOWOUT PANEL - pulse attenuation by redirection and damping
Figure 42 also shows the bypass routes offered by blowout panels locations just inside of the boundary so as to divert the pulse into the capacitive effects of the fan room. The bypass branches are simulated as dampers with a programmed opening resistance versus time ramp.
The idea of bypassing the pulse into the fan room as soon as it entered the building produced the result of saving the fan units at the expense of the internal ducting as seen in Figure 44.

CONCLUSIONS

1. The most direct route to ensuring the survival of the EPS and EPG building ventilation system ducting and fans in the event of a Design Basis Tornado would be to install tornado dampers at the inlet and exhaust peripheral points to prevent the ingress of damaging pressure transients. This would be a much more economical approach than testing full scale samples of all the affected internal ducts and fans with no prior guarantee that the eventual outcome would not point to tornado dampers anyway.
2. It does not appear to be necessary, if all other louvres of the EPG building are protected by tornado dampers, to install such dampers in the louvre openings of the battery rooms of that building.

Approved:

for

G.J.Clarke
Manager
Mechanical Research Department
Mechanical Research Division

Submitted:

J.W.R.Jackson
Engineer
Mechanical Testing and Development Section
Mechanical Research Department

DISTRIBUTION

Mr.K.S. Guise	Darlington Project	H16A09
Mr.H. Souw	Darlington Project	H16B09
Mr.A.S. Lemanski	Plant Processes	H14A27
Mr.J.W. Blyth	N.S. & S.	H11F18
Mr.K. Garel	O.S. & S.	H11A06
Mr.F.W. Doyle	O.S. & S.	H11A09
Mr. D.B. Craig	Mechanical Research	
Mr. N.S.D'Silva	Mechanical Research	
Mr. J.W.R. Jackson	Mechanical Research	

Public Reference Centre
Editorial Section (2)
Office Copies (2)
Extra Copies (3)

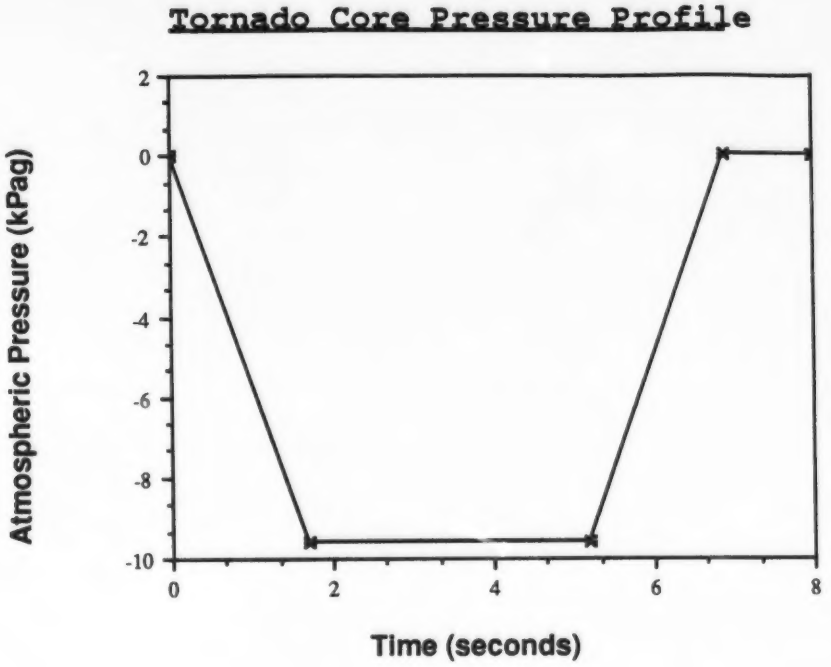


Figure 1
Tornado Depressurization Profile

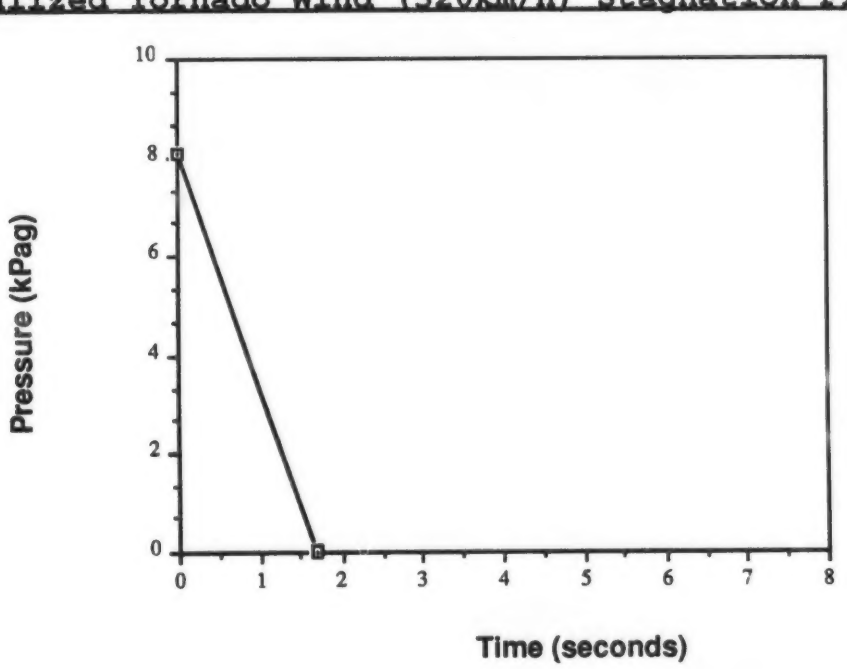


Figure 2
Idealized Tornado Wind Pressure Profile

Figure 3
EPS Building - Rear View

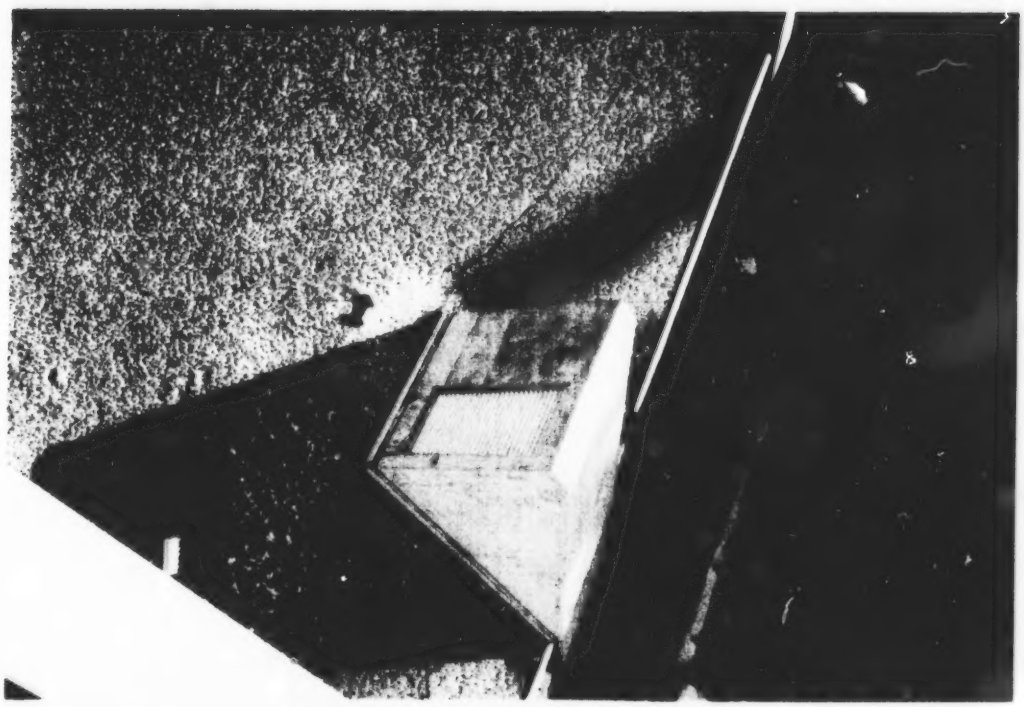


Figure 4
EPS Building Exhaust Louvre

Figure 5
EPS Building Inlet Louvre

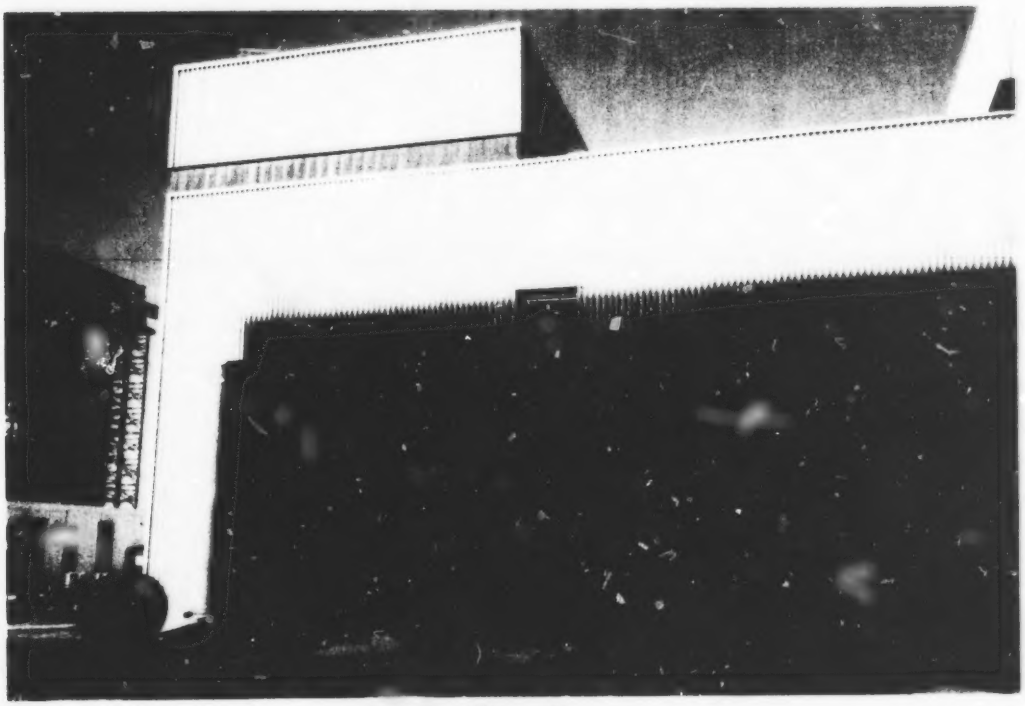


Figure 6
EPG Building Inlet Louvre

Figure 7
EPG Building Exhaust Louvres and Battery Room Louvre (small)

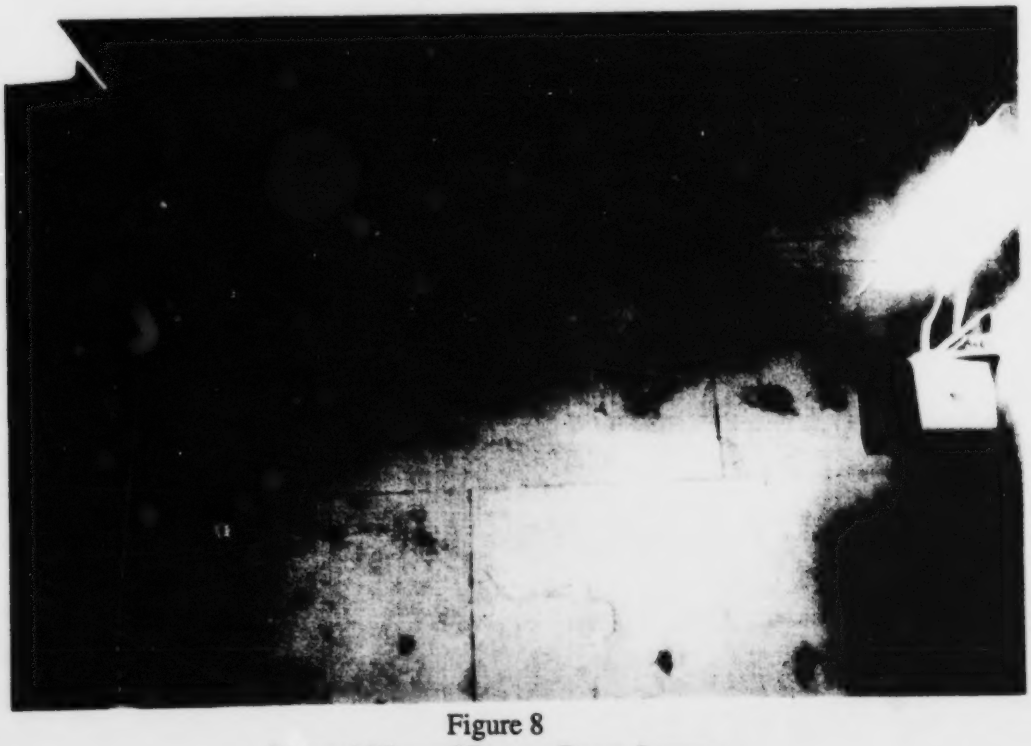


Figure 8
Internal View of Battery Room Louvre

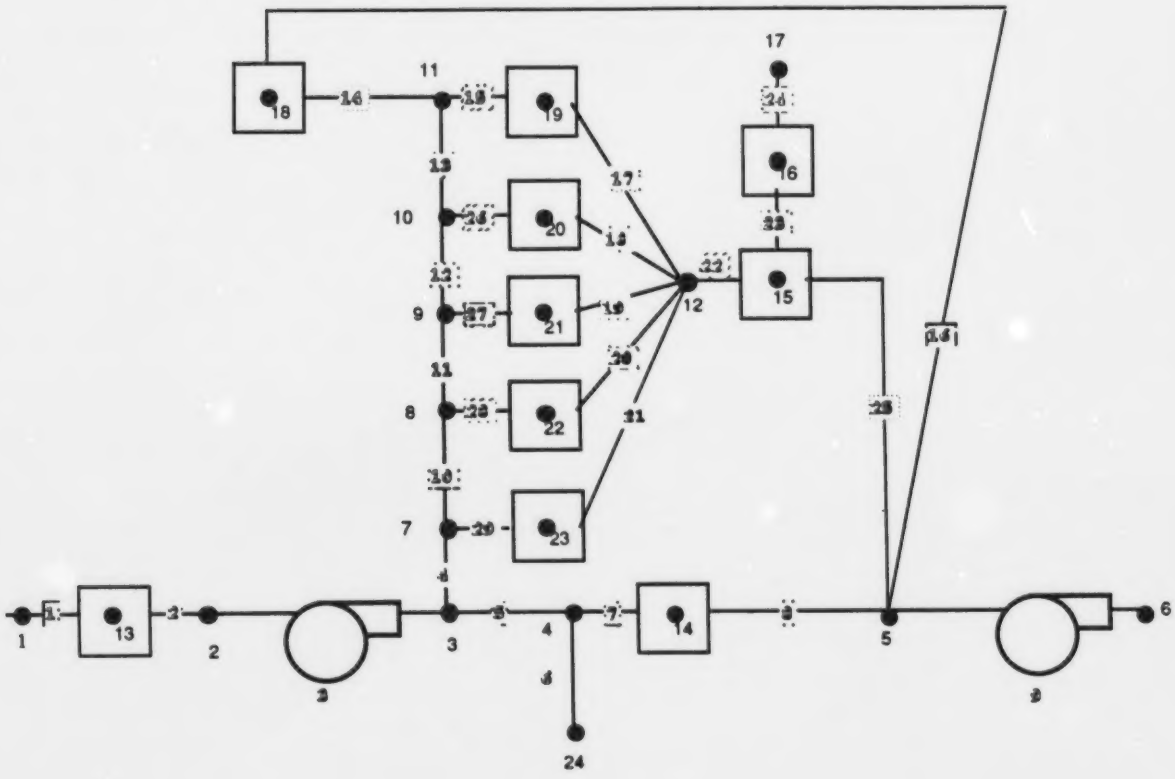


Figure 9
EPS Building - Summer Configuration - Schematic

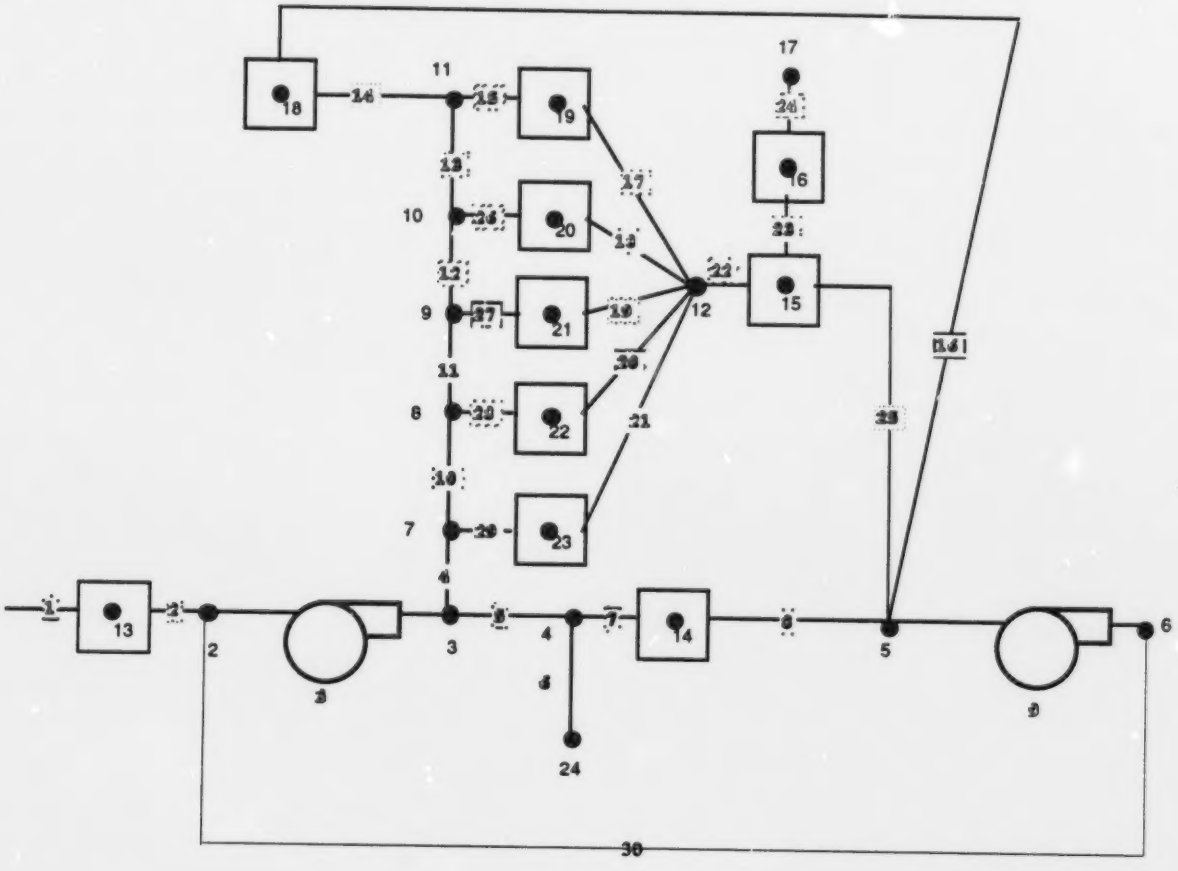


Figure 10
EPS Building - Winter Configuration - Schematic

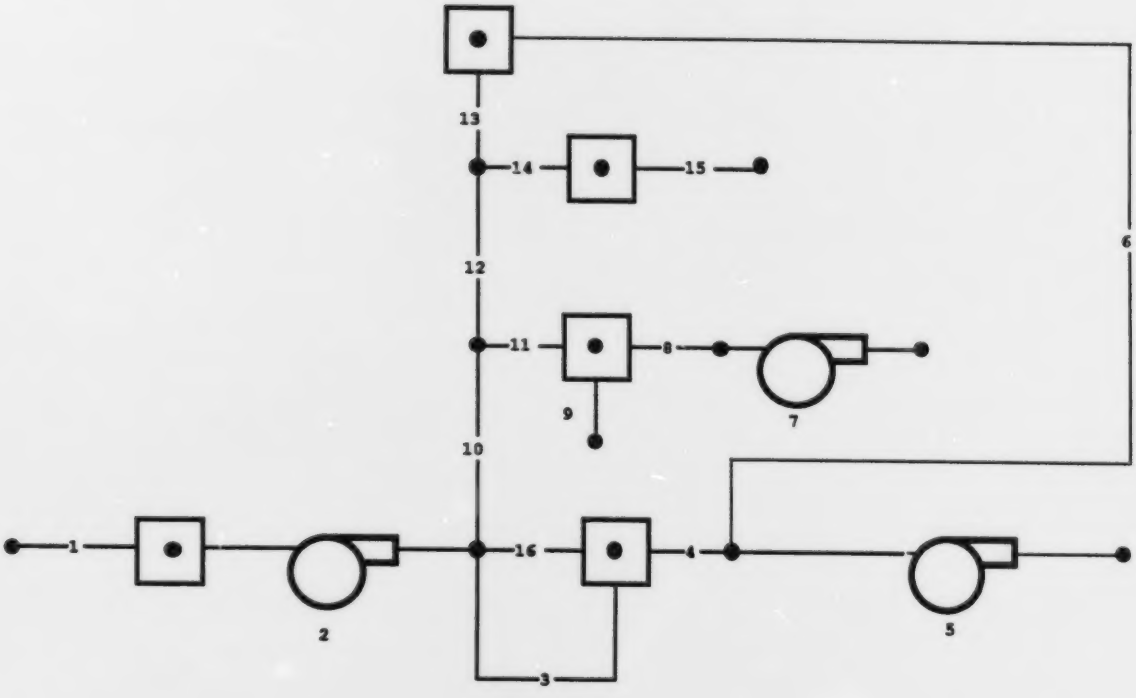


Figure 11
EPG Building - Summer Configuration - Schematic

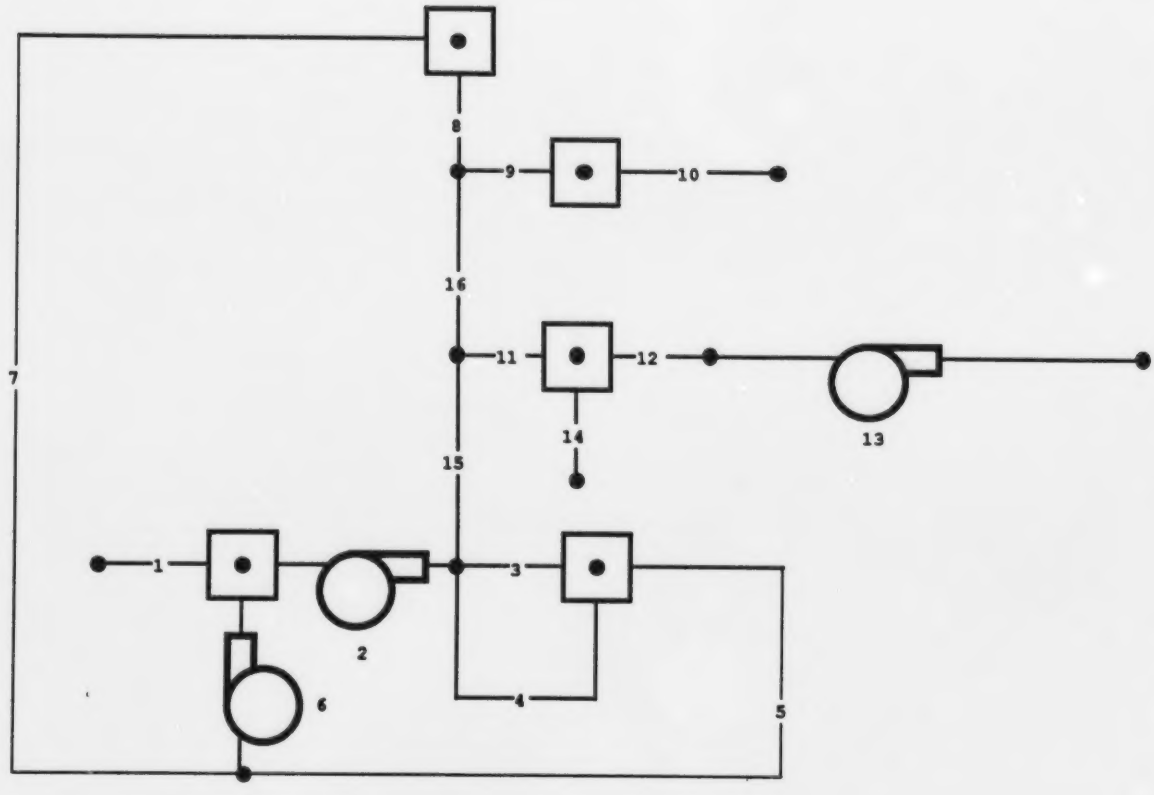


Figure 12
EPG Building - Winter Configuration - Schematic

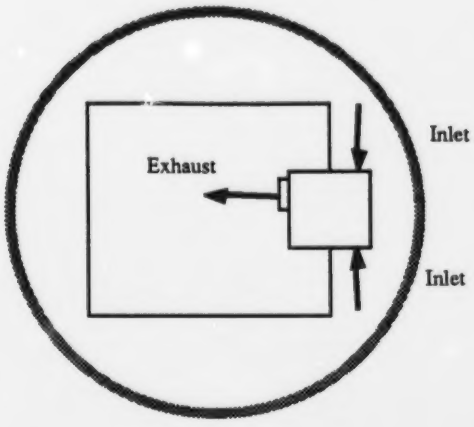


Figure 13
Plan View of EPS Building - Tornado Passing Through

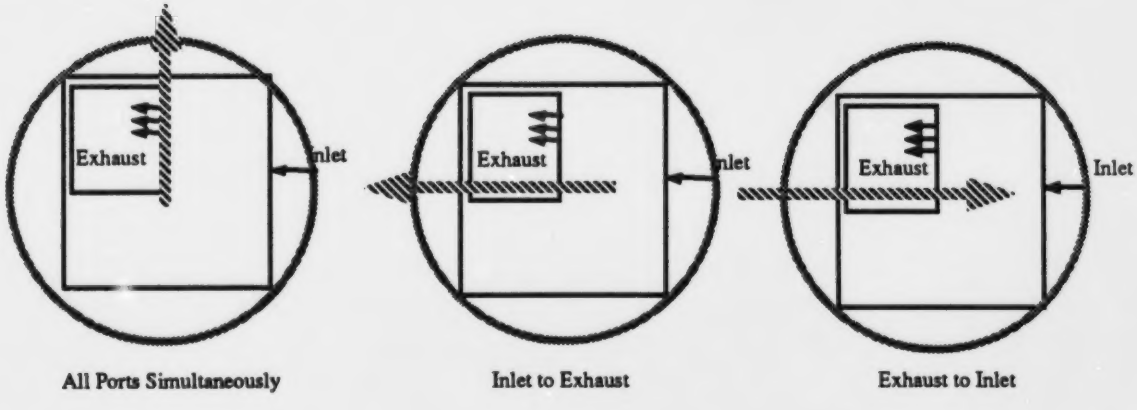


Figure 14
Plan View of EPG Building - Tornado Approach Scenarios

EPS Building - Summer Configuration
Tornado at all ports

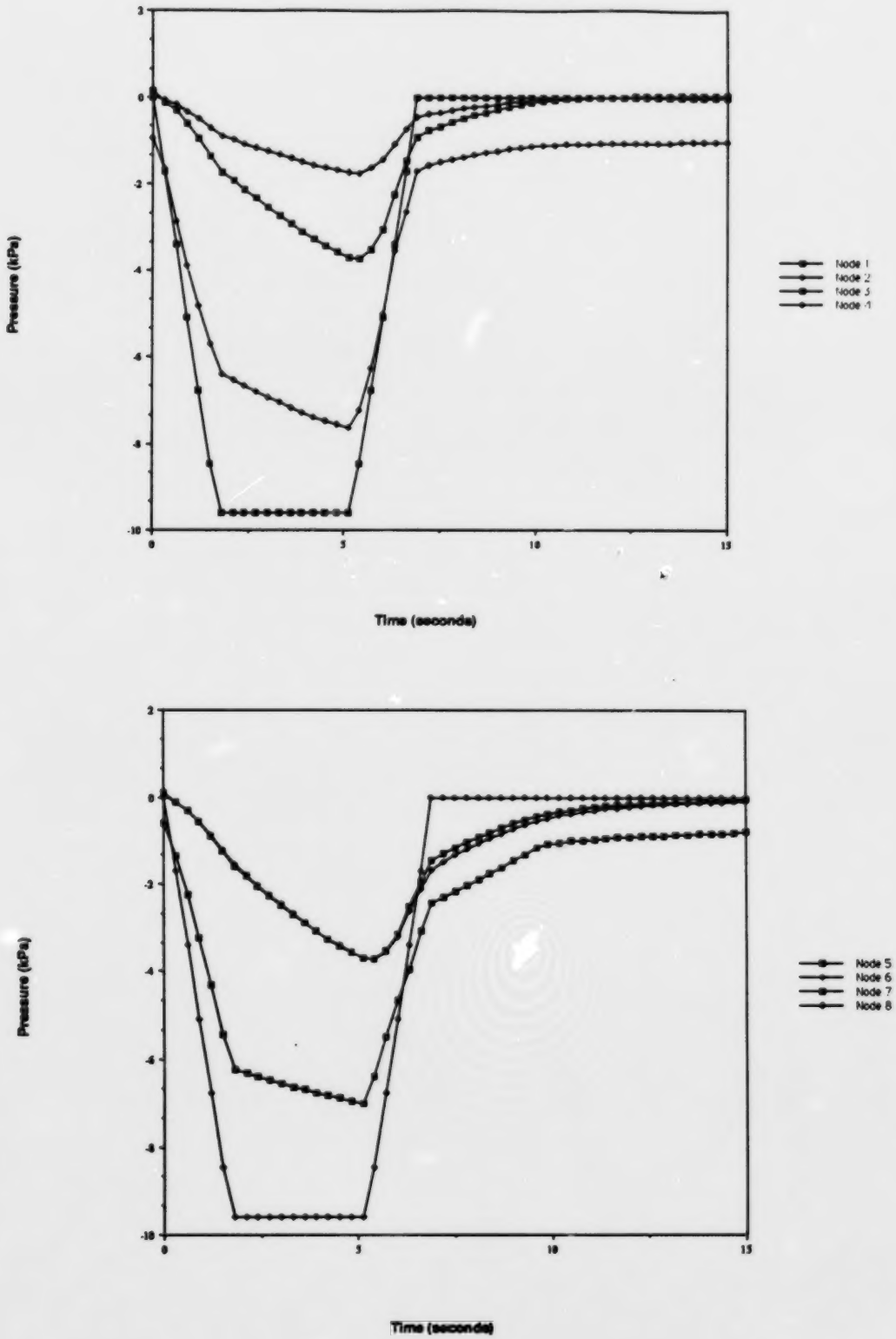
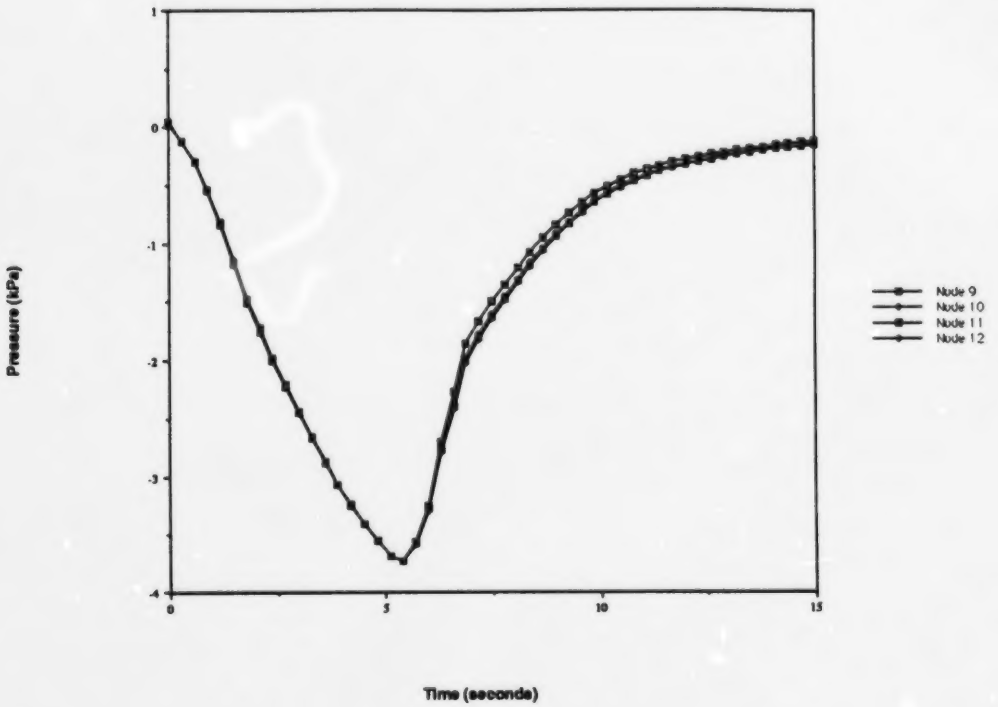


Figure 15


Pressure (kPa)
1
0
-1
-2
-3
-4
0
5
10
15
Time (seconds)
Node 9
Node 10
Node 11
Node 12

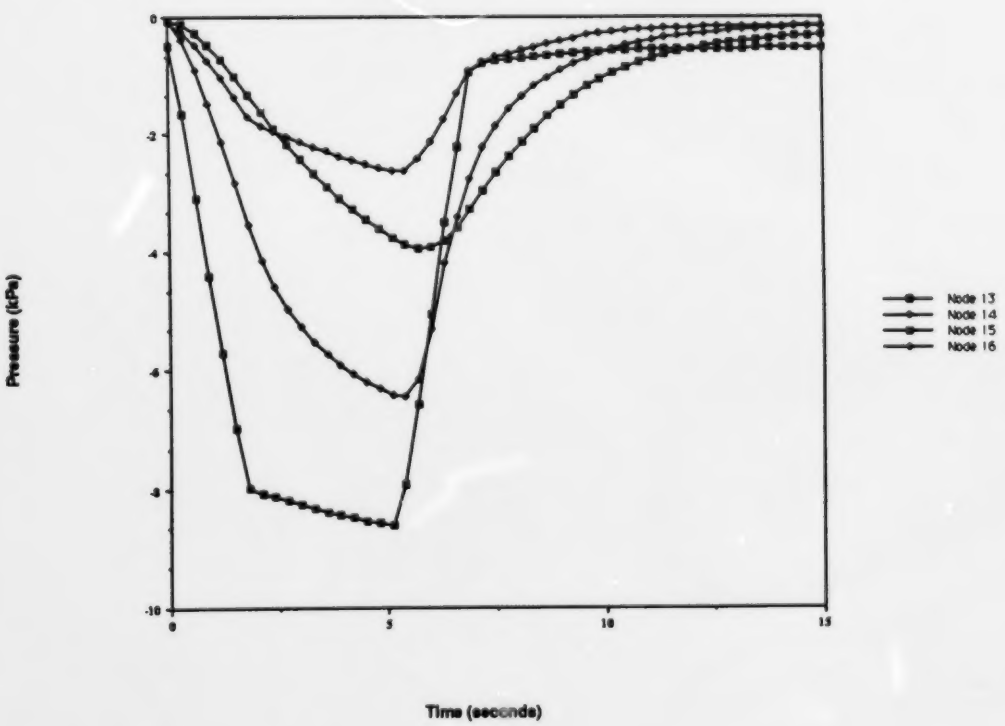
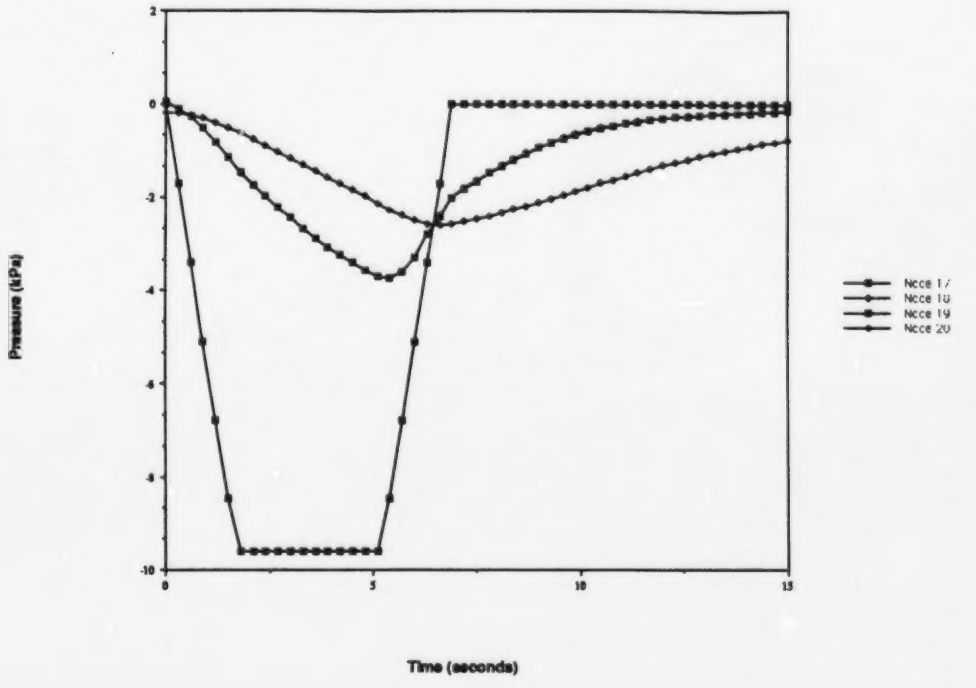

Pressure (kPa)
0
-2
-4
-6
-8
-10
0
5
10
15
Time (seconds)
Node 13
Node 14
Node 15
Node 16

Figure 16


Pressure (kPa)
Time (seconds)
Node 17
Node 18
Node 19
Node 20

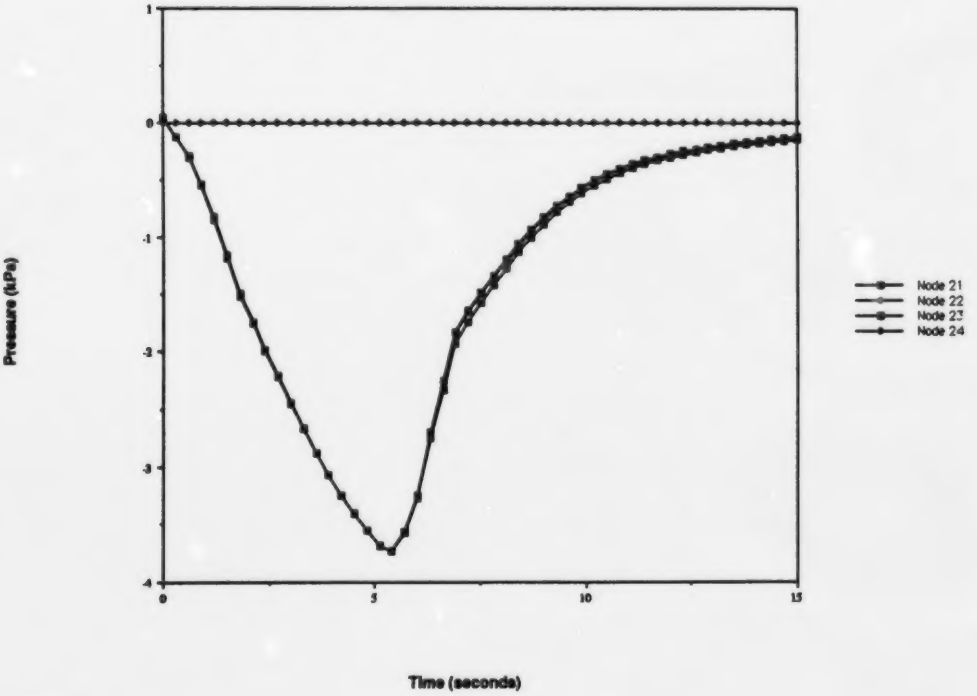
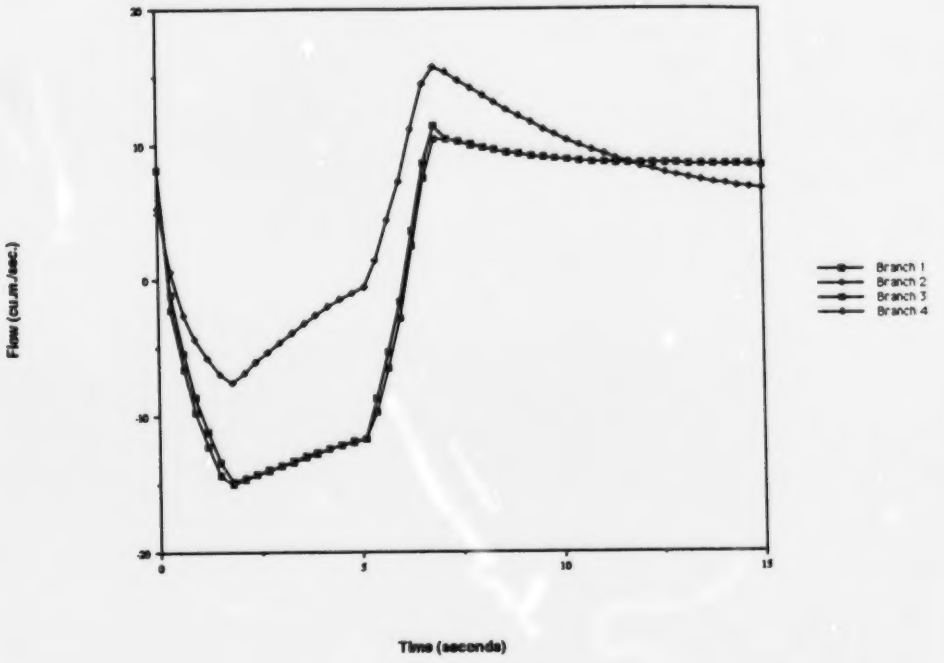

Pressure (kPa)
Time (seconds)
Node 21
Node 22
Node 23
Node 24

Figure 17

EPS Building - Summer Configuration
Flow Profiles



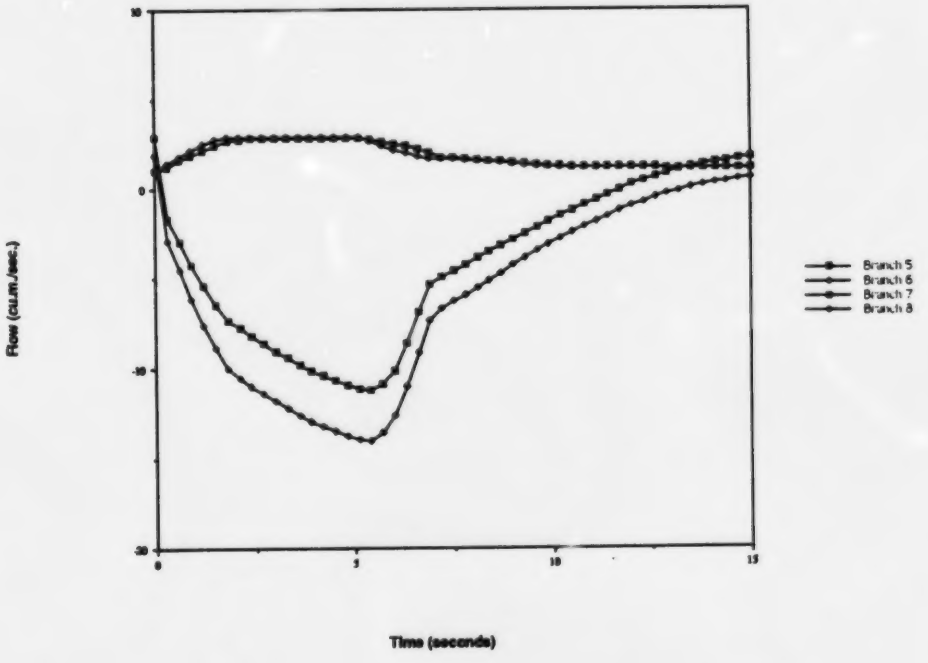


Figure 18

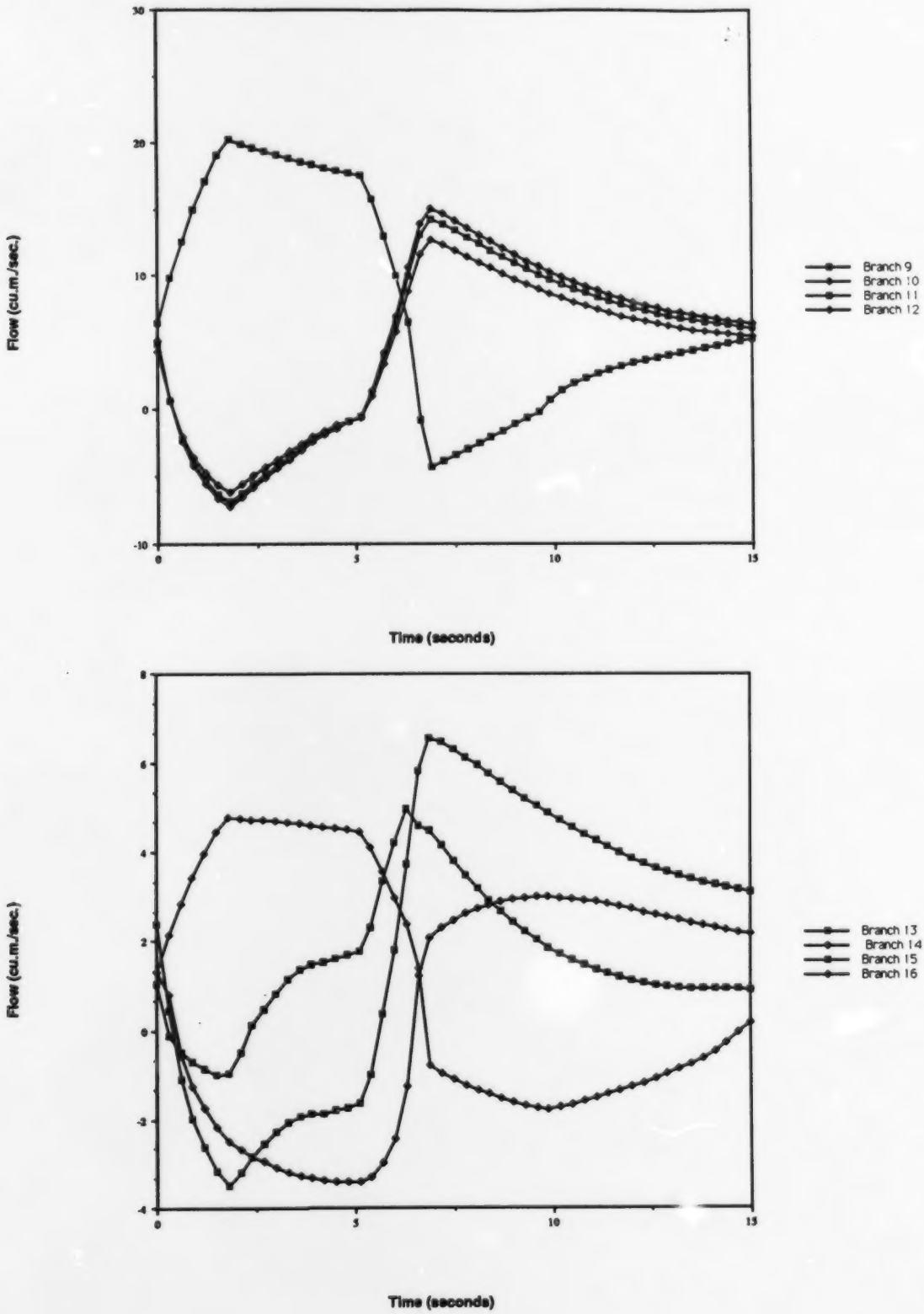

Flow (cu.m./sec.)
30
20
10
0
-10
0
5
10
15
Time (seconds)
Branch 9
Branch 10
Branch 11
Branch 12
Flow (cu.m./sec.)
8
6
4
2
0
-2
-4
0
5
10
15
Time (seconds)
Branch 13
Branch 14
Branch 15
Branch 16

Figure 19

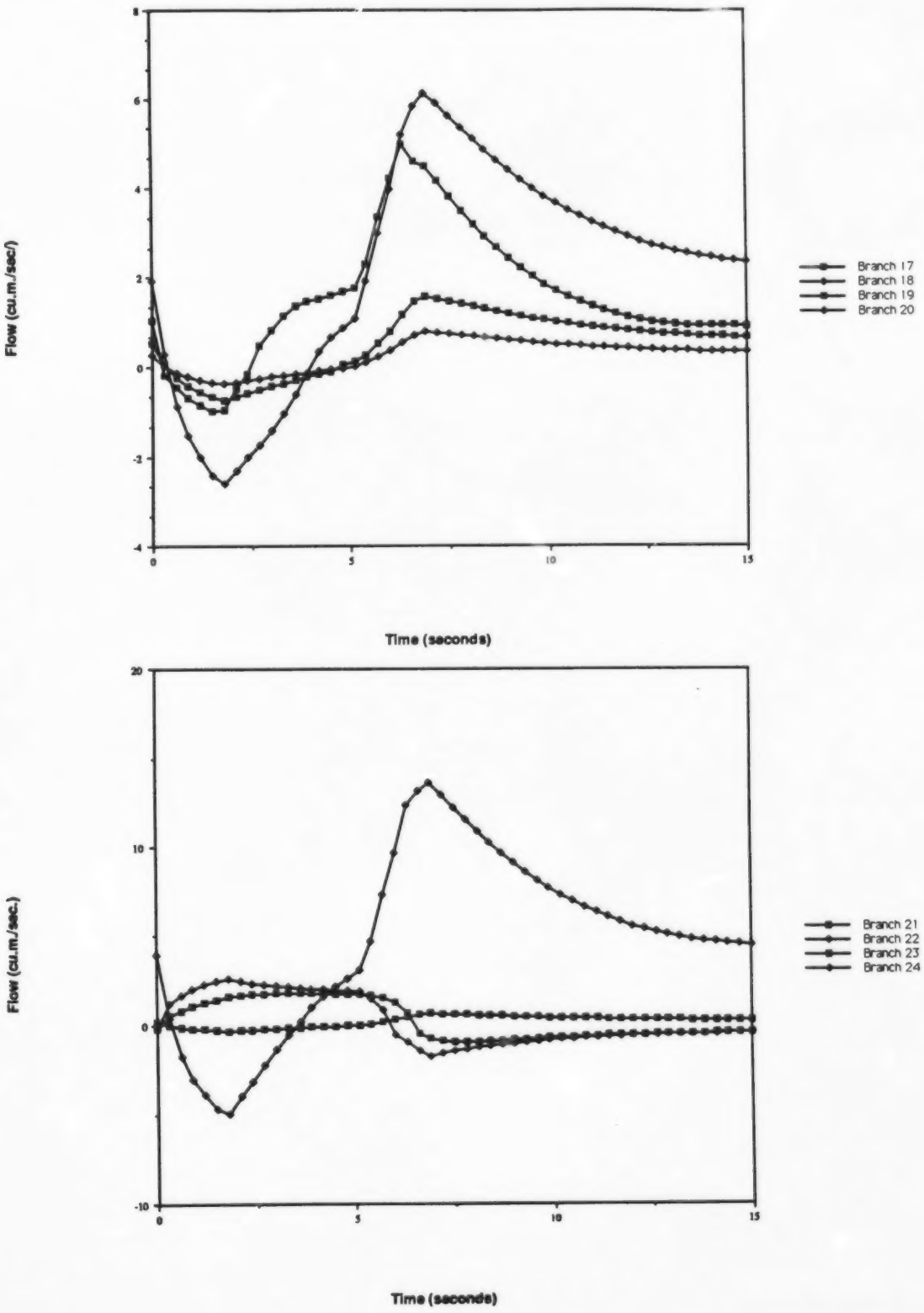

Flow (cu.m./sec)
Time (seconds)
Branch 17
Branch 18
Branch 19
Branch 20
Flow (cu.m./sec.)
Time (seconds)
Branch 21
Branch 22
Branch 23
Branch 24

Figure 20

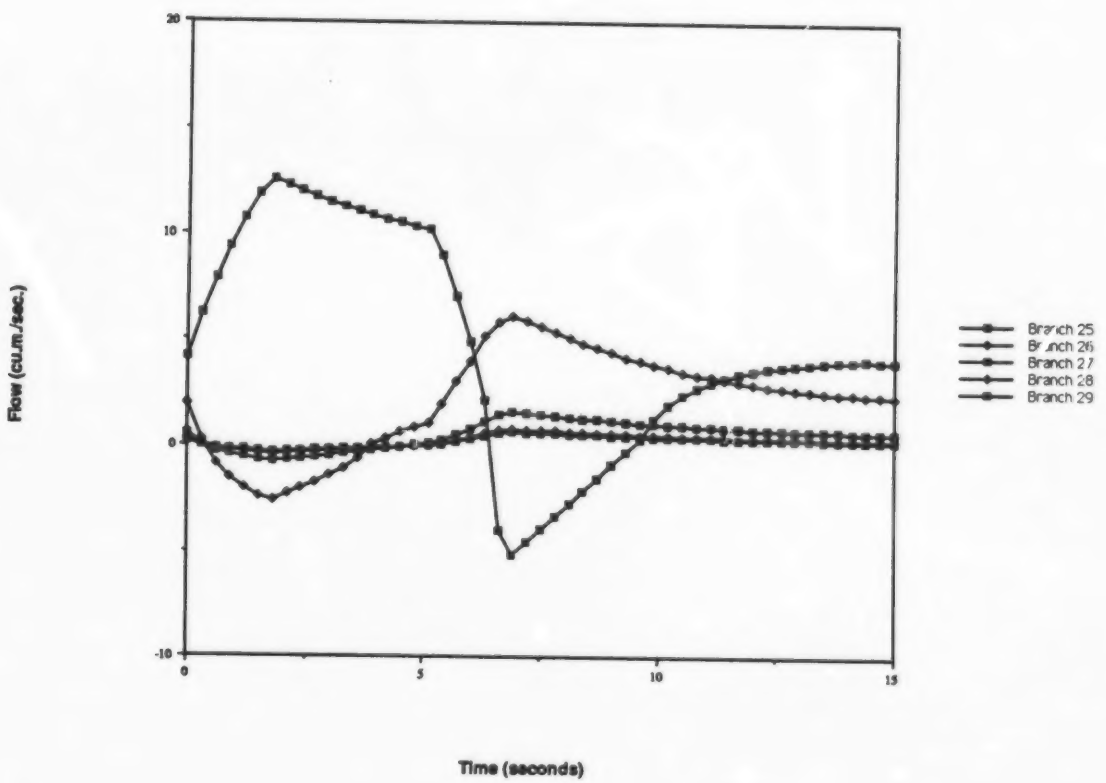

Flow (cu.m./sec.)
20
10
0
-10
0
5
10
15
Time (seconds)
Branch 25
Branch 26
Branch 27
Branch 28
Branch 29

Figure 21

EPS Building - Summer Configuration -
Tornado at All Ports Simultaneously

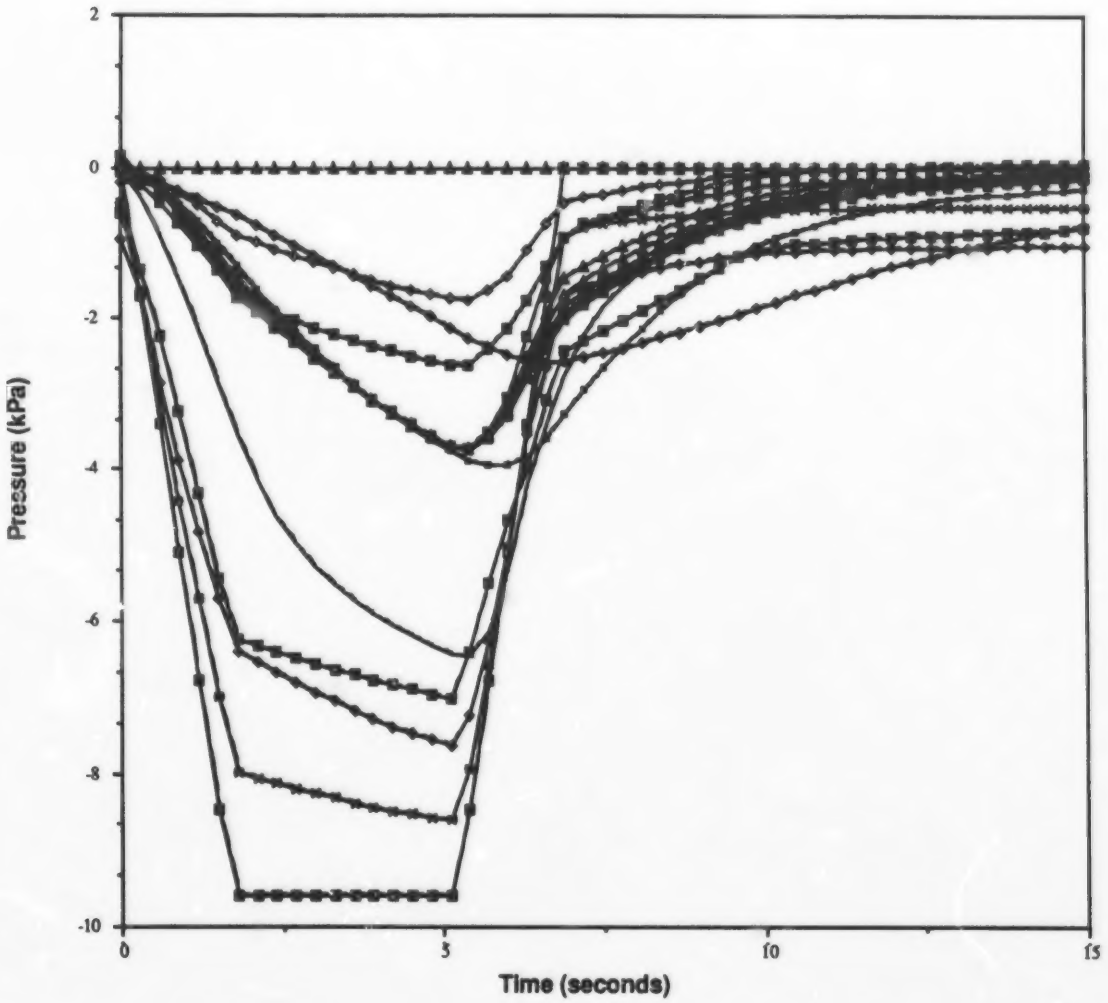


Figure 22
Combined EPS Summer Plots

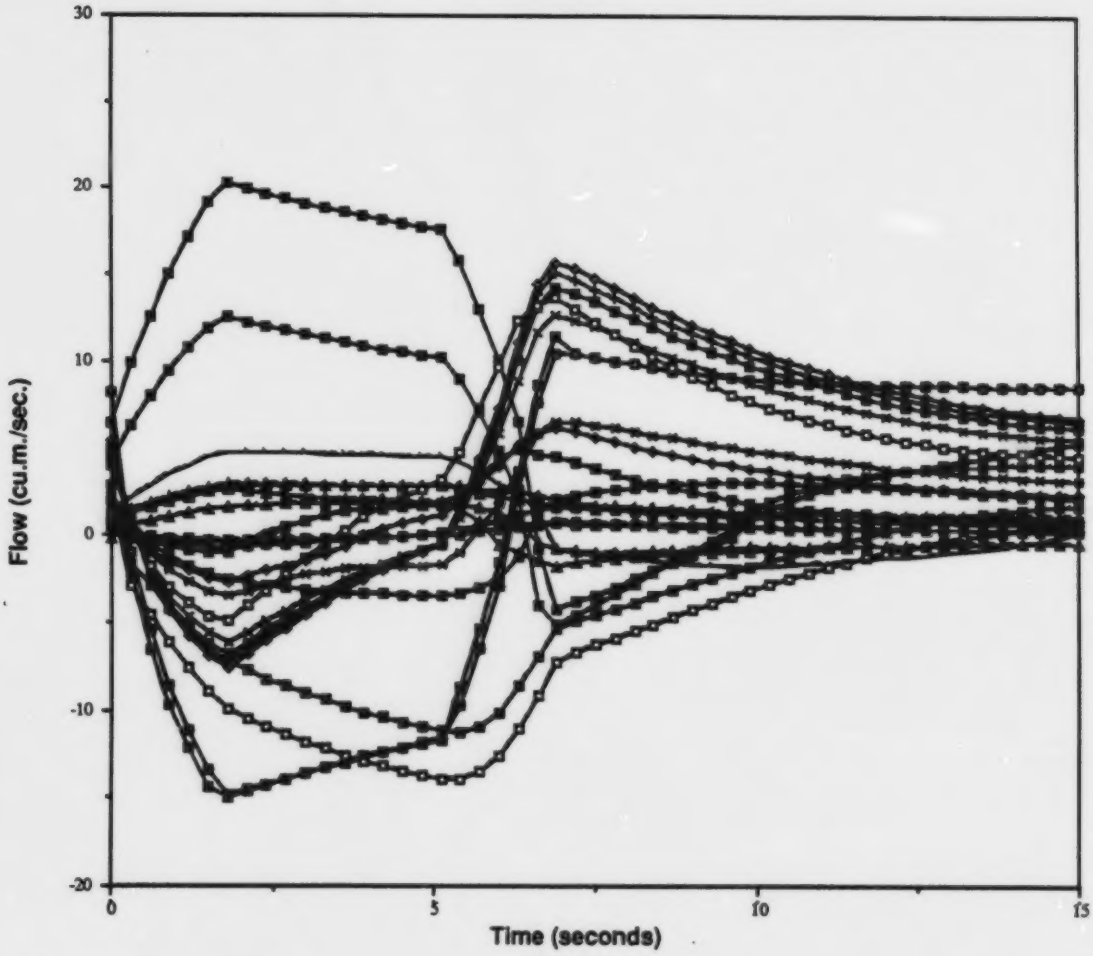


Figure 23
Combined Flow Plots for EPS Summer

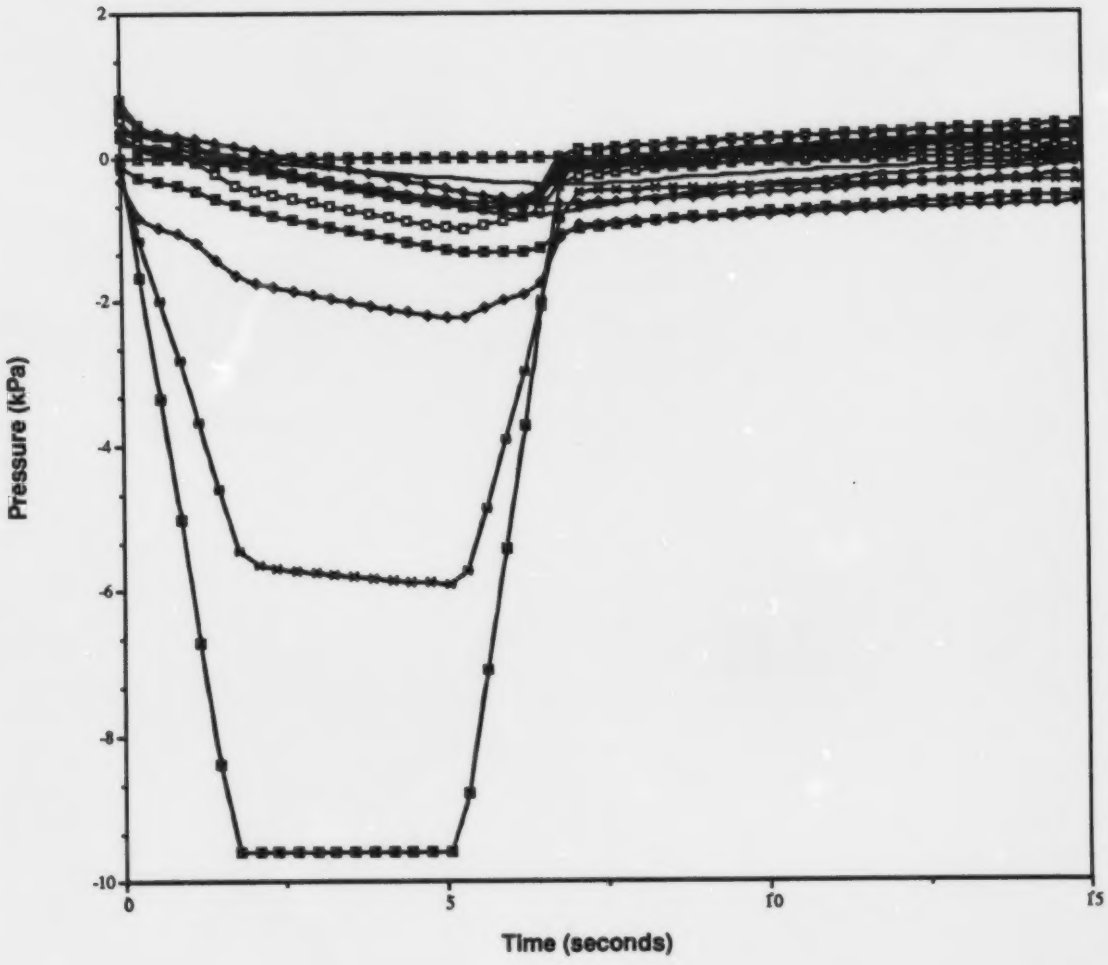


Figure 24
Combined Pressure Plots for EPS Winter

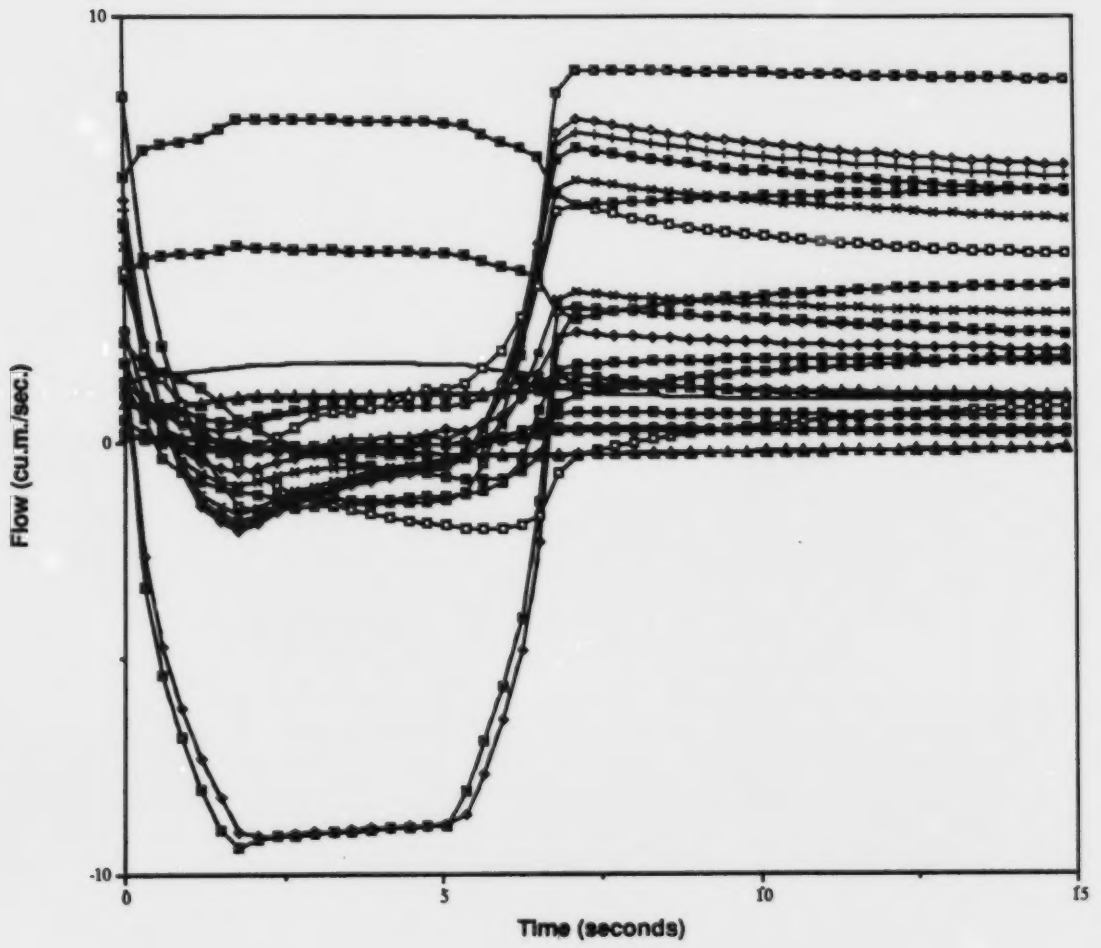


Figure 25
Combined Flow Plots for EPS Winter

EPG Building - Summer Configuration
All Ports Simultaneously

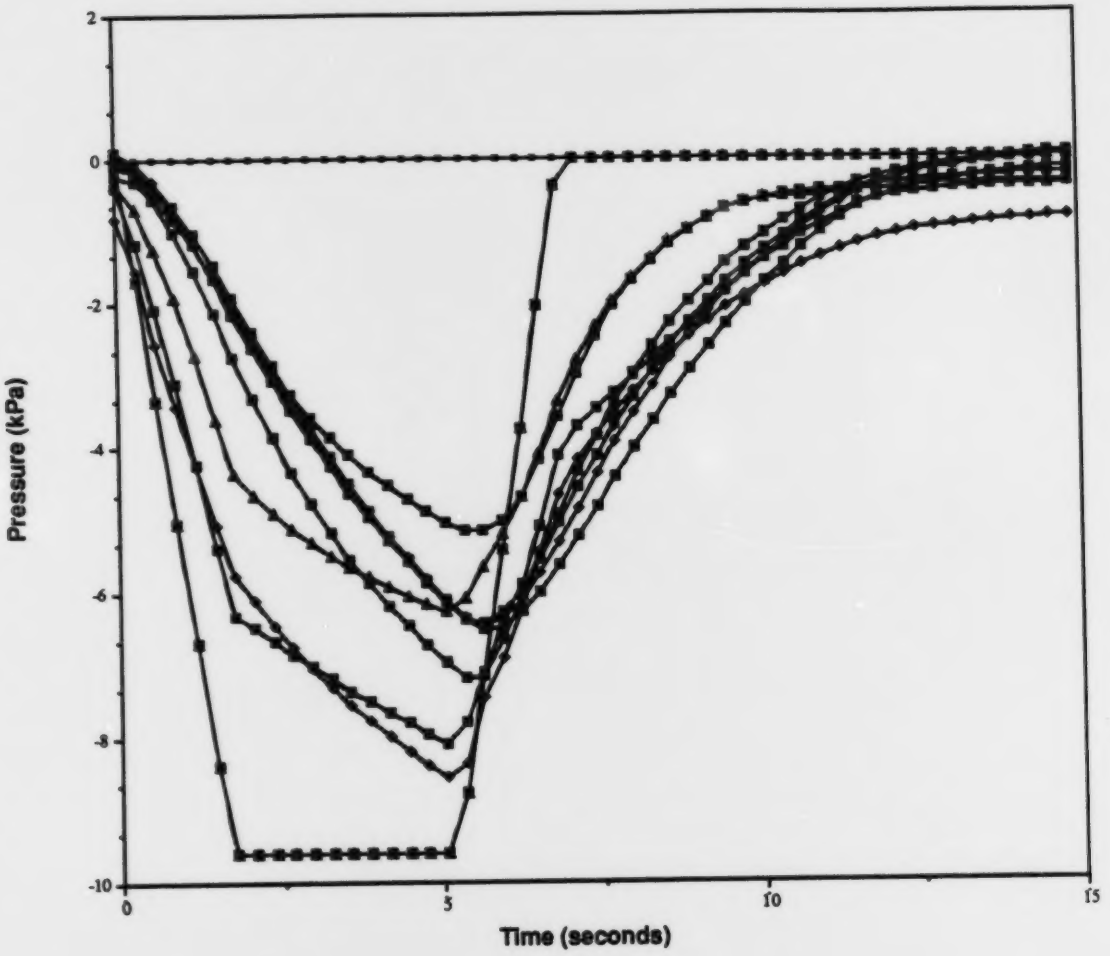


Figure 26
Combined Pressure Plots for EPG Summer

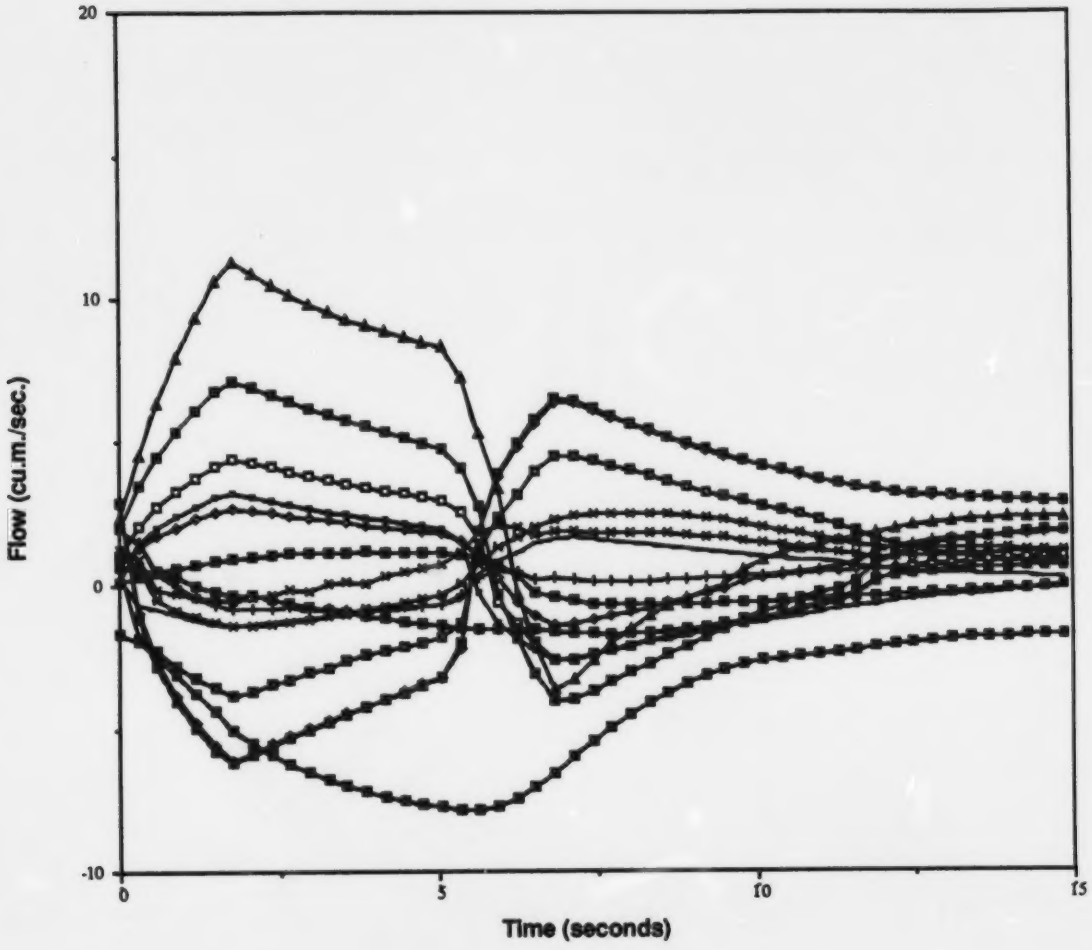


Figure 27
Combined Flow Plots for EPG Summer

EPG Building - Winter Configuration
All Ports Simultaneously

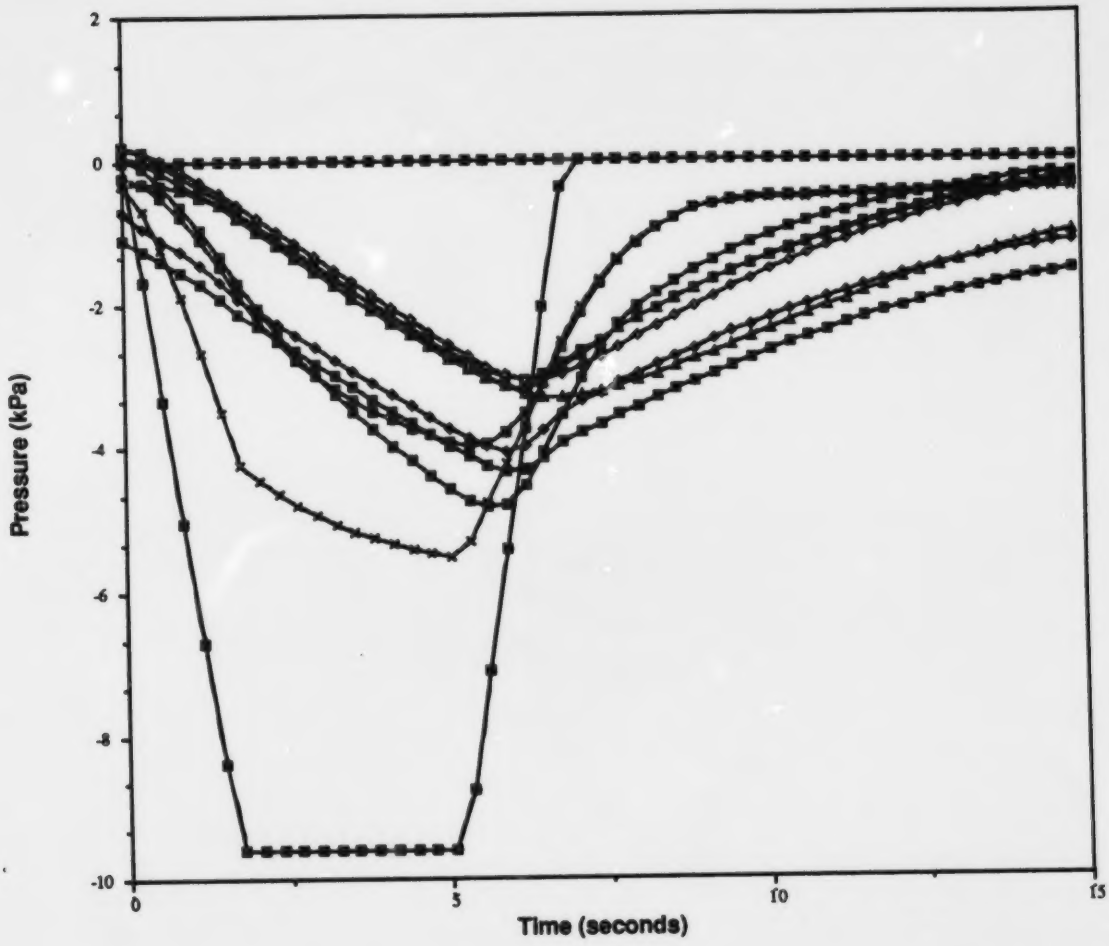


Figure 28
Combined Pressure Plots for EPG Winter

EPG Building - Winter Configuration
All Ports Simultaneously

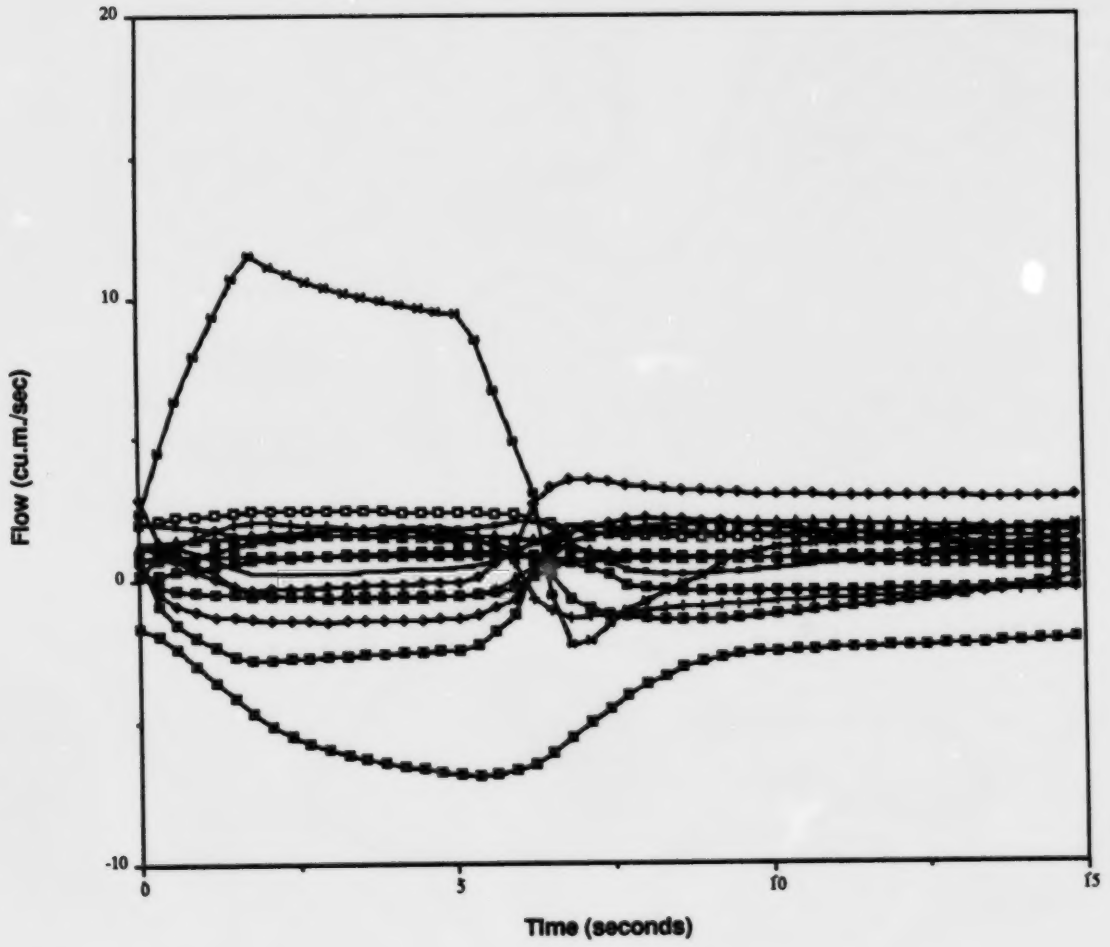
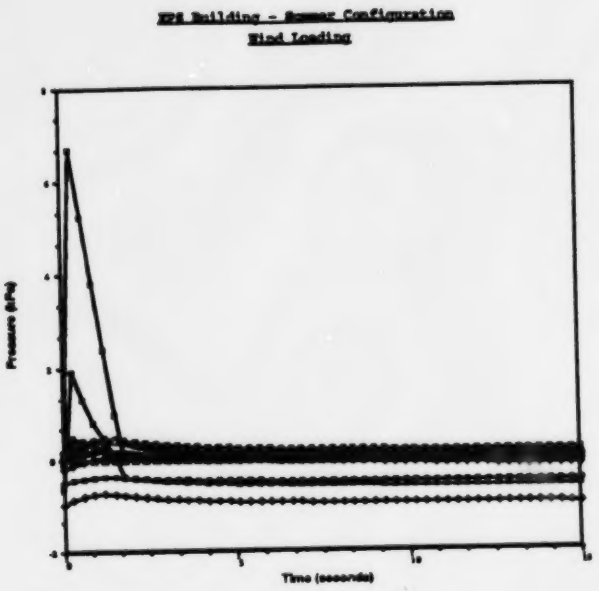


Figure 29
Combined Flow Plots for EPG Winter



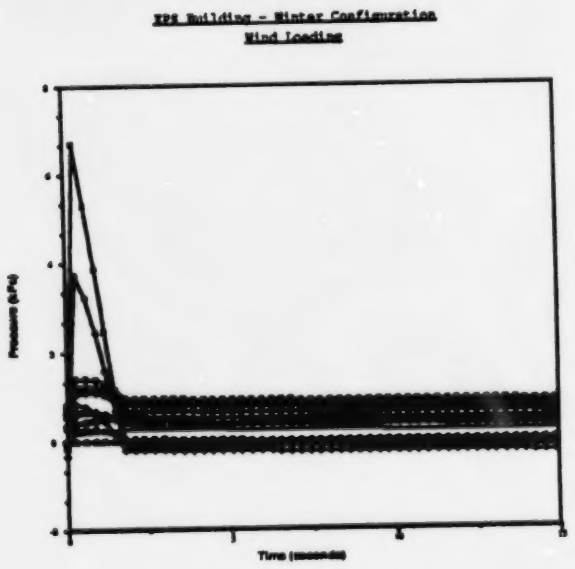
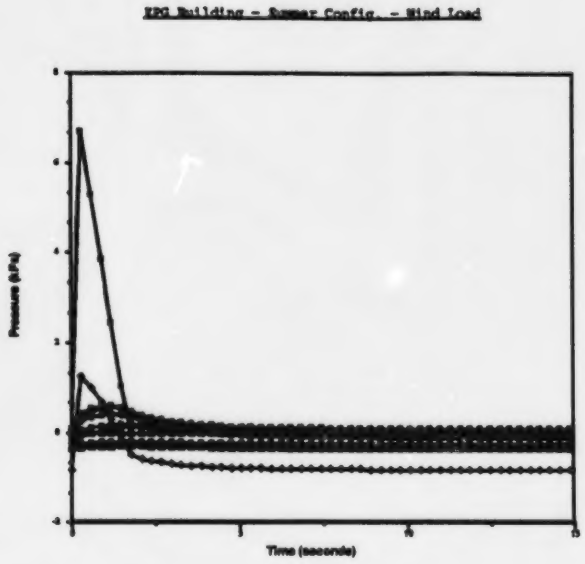


Figure 30
Wind Stagnation Effect on EPS Building



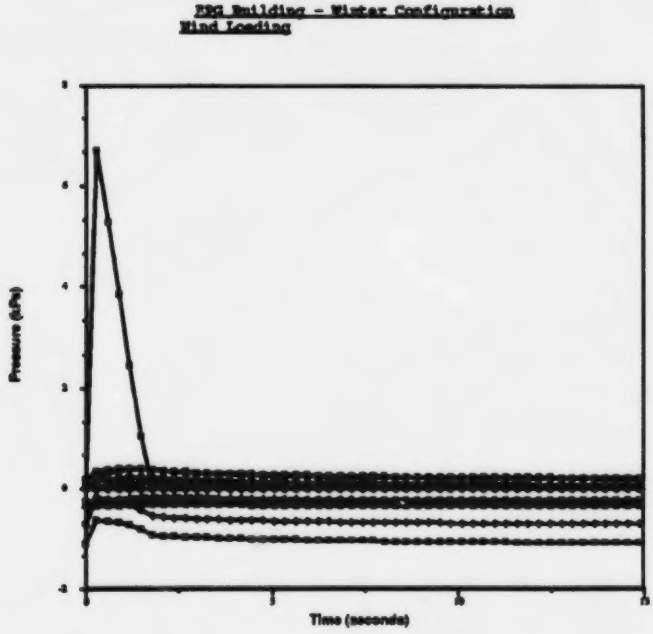


Figure 31
Wind Stagnation Effect on EPG Building

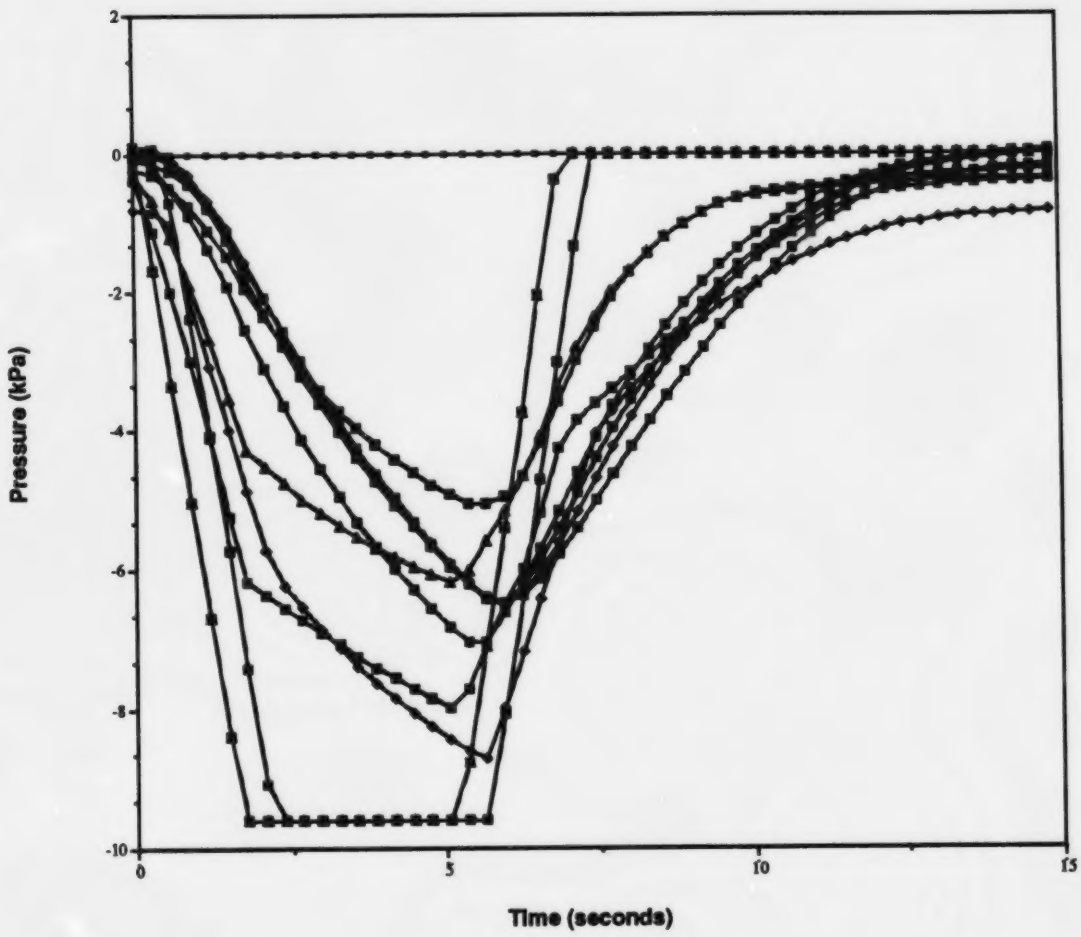


Figure 32
Pressure Effect With Tornado Passing from Inlet to Exhaust

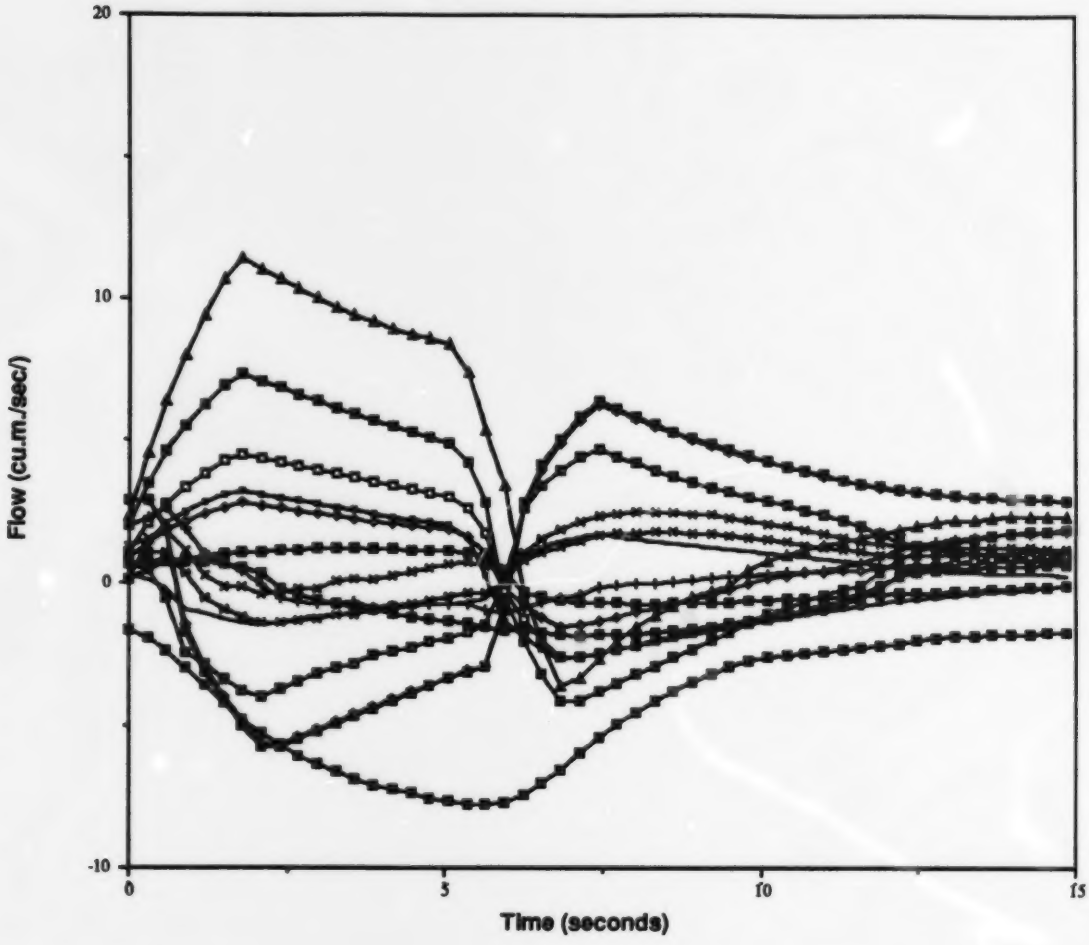


Figure 33
Flow Effect With Tornado Passing from Inlet to Exhaust

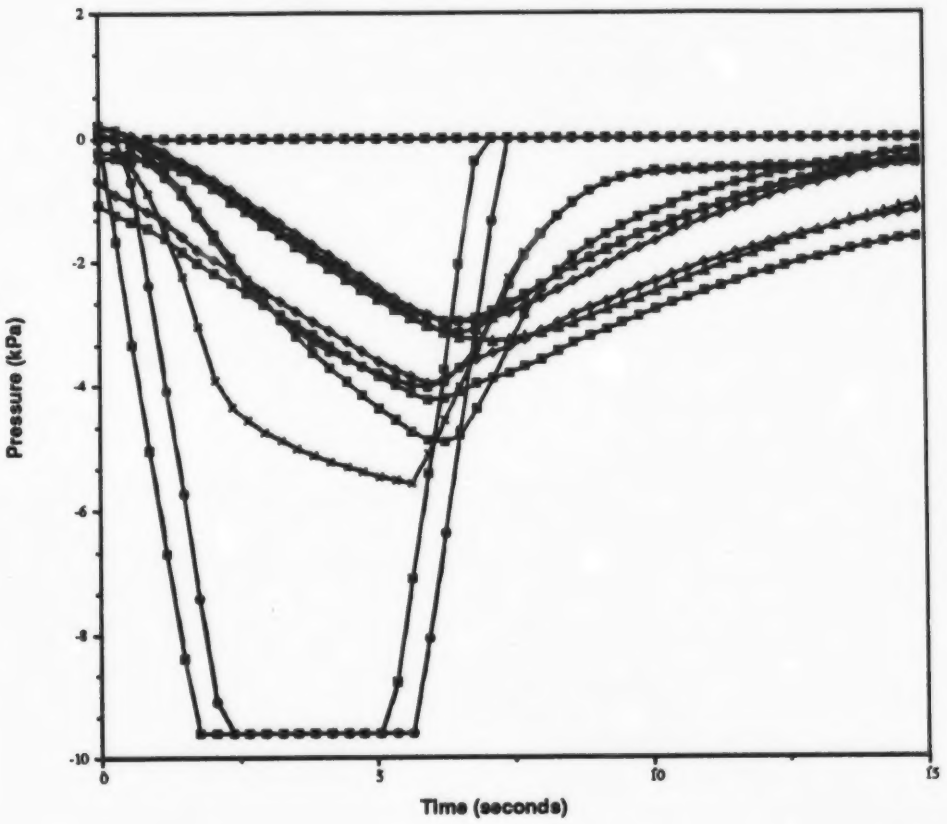


Figure 34
Winter Configuration With Passage from Inlet to Exhaust

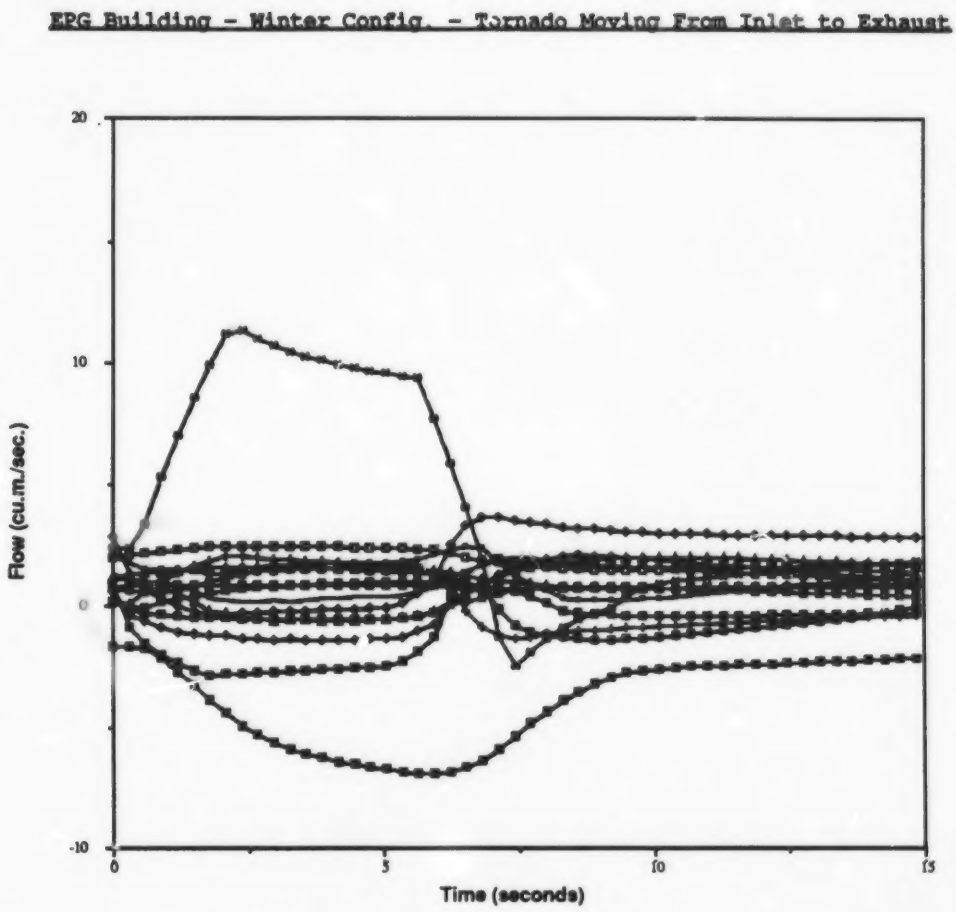


Figure 35
Winter Configuration Flow With Passage fron Inlet to Exhaust

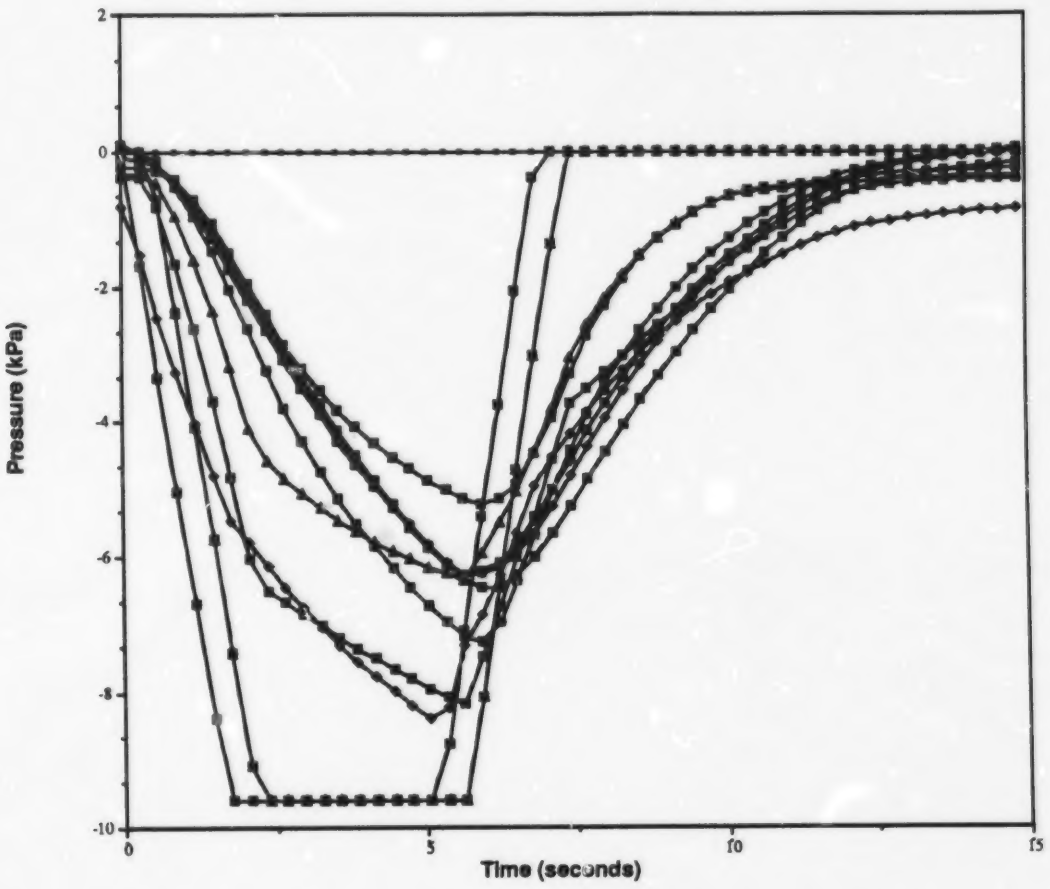


Figure 36
Pressure Profiles Resulting FromPassage of Tornado From Exhaust to Inlet

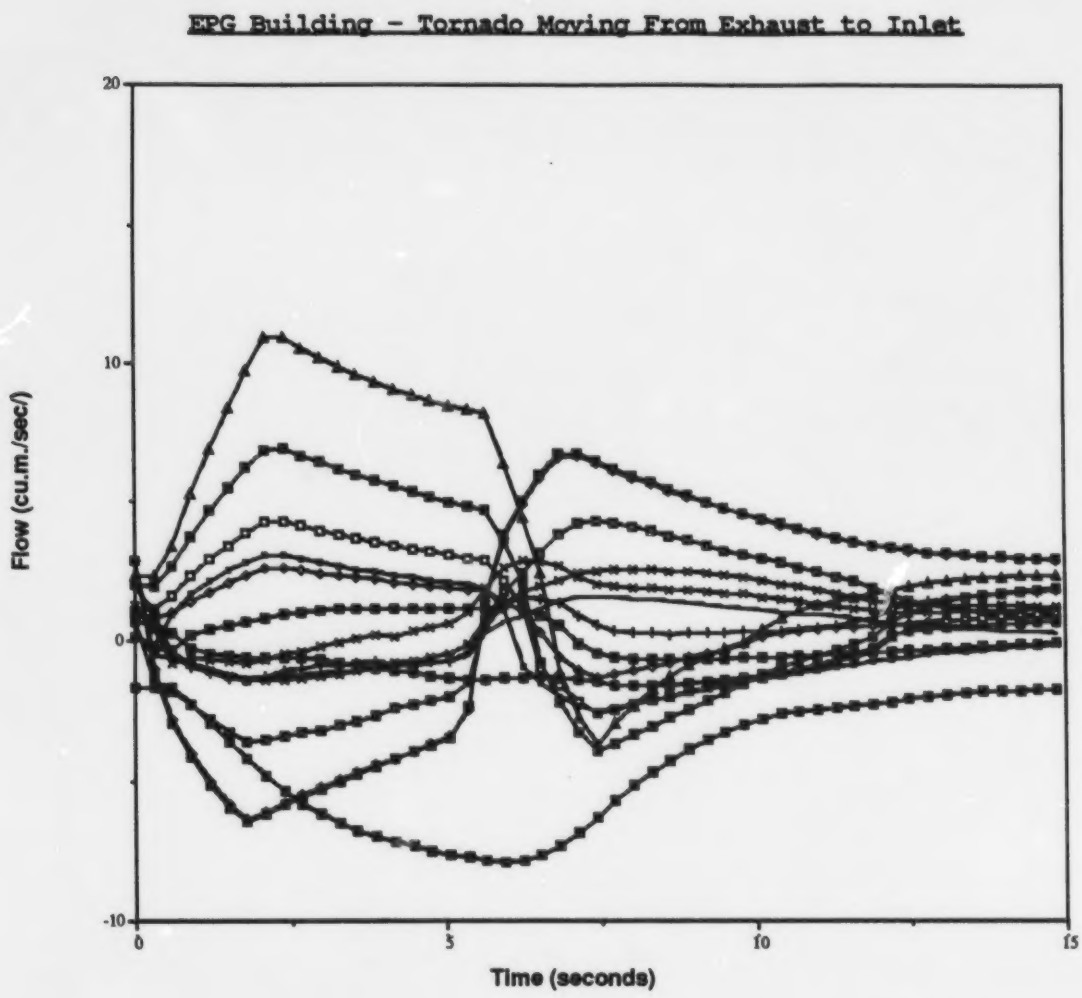


Figure 37
Flow Profiles Resulting FromPassage of Tornado From Exhaust to Inlet

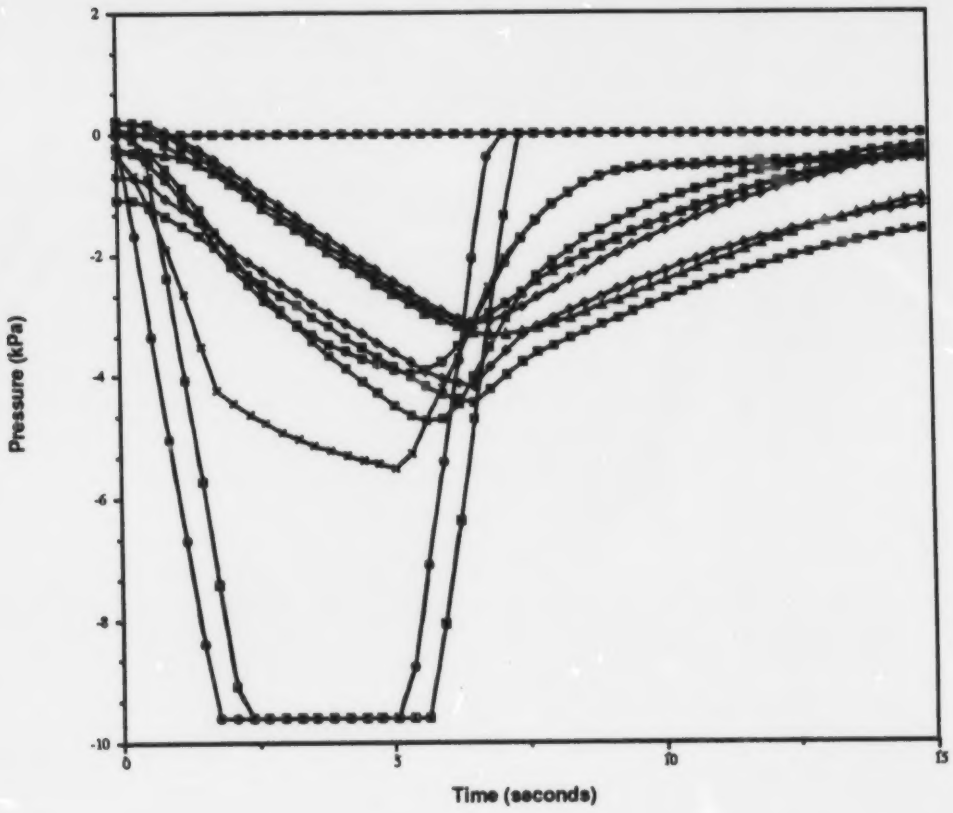


Figure 38
Pressure Profiles Resulting FromPassage of Tornado From Exhaust to Inlet - Winter

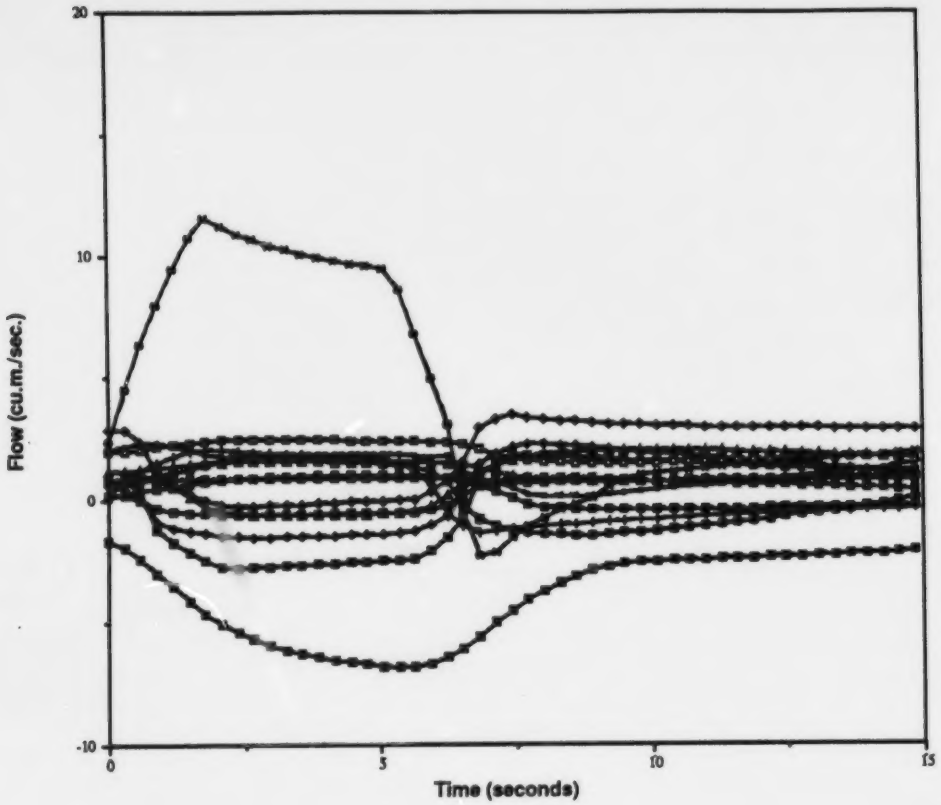


Figure 39
Flow Profiles Resulting From Passage of Tornado From Exhaust to Inlet - Winter

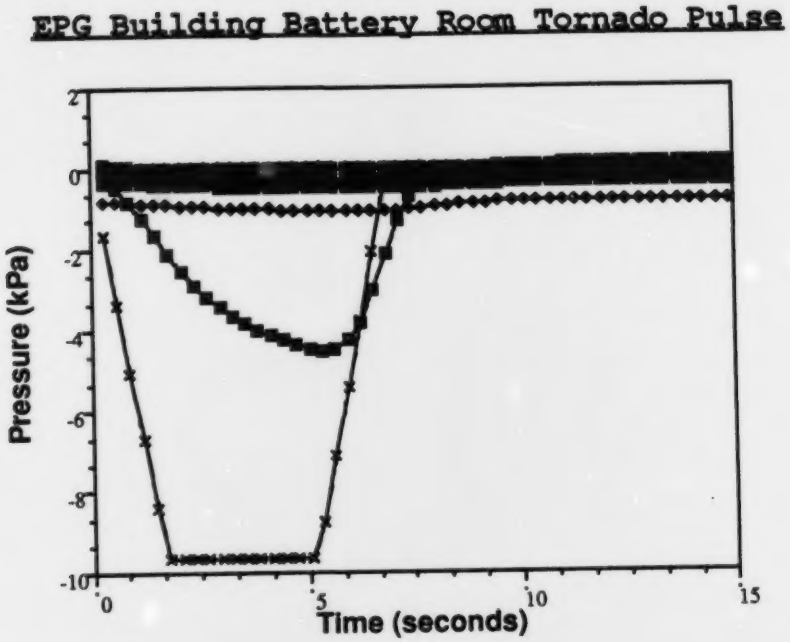


Figure 40
Pressure Due to Tornado at EPG Battery Room Louvre Only

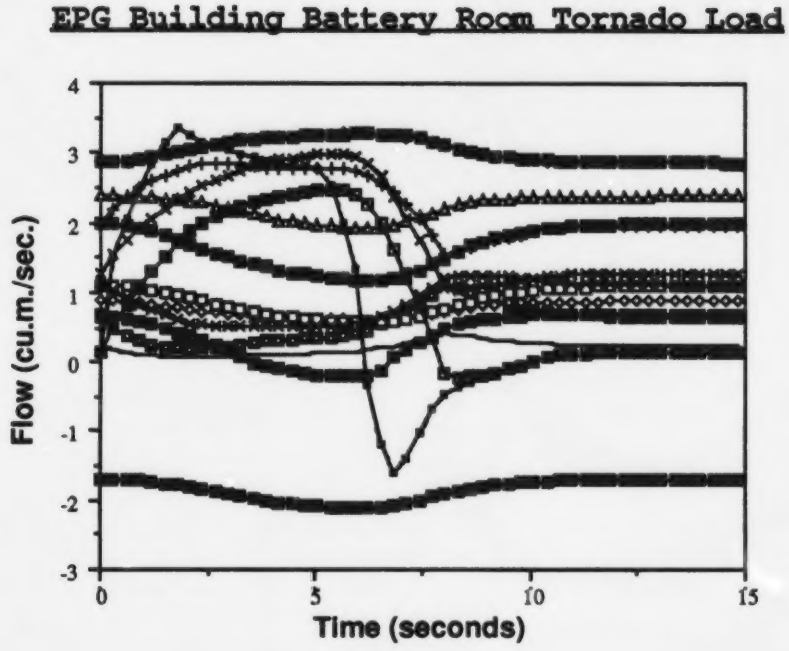


Figure 41
Flow Due to Tornado at EPG Battery Room Louvre Only

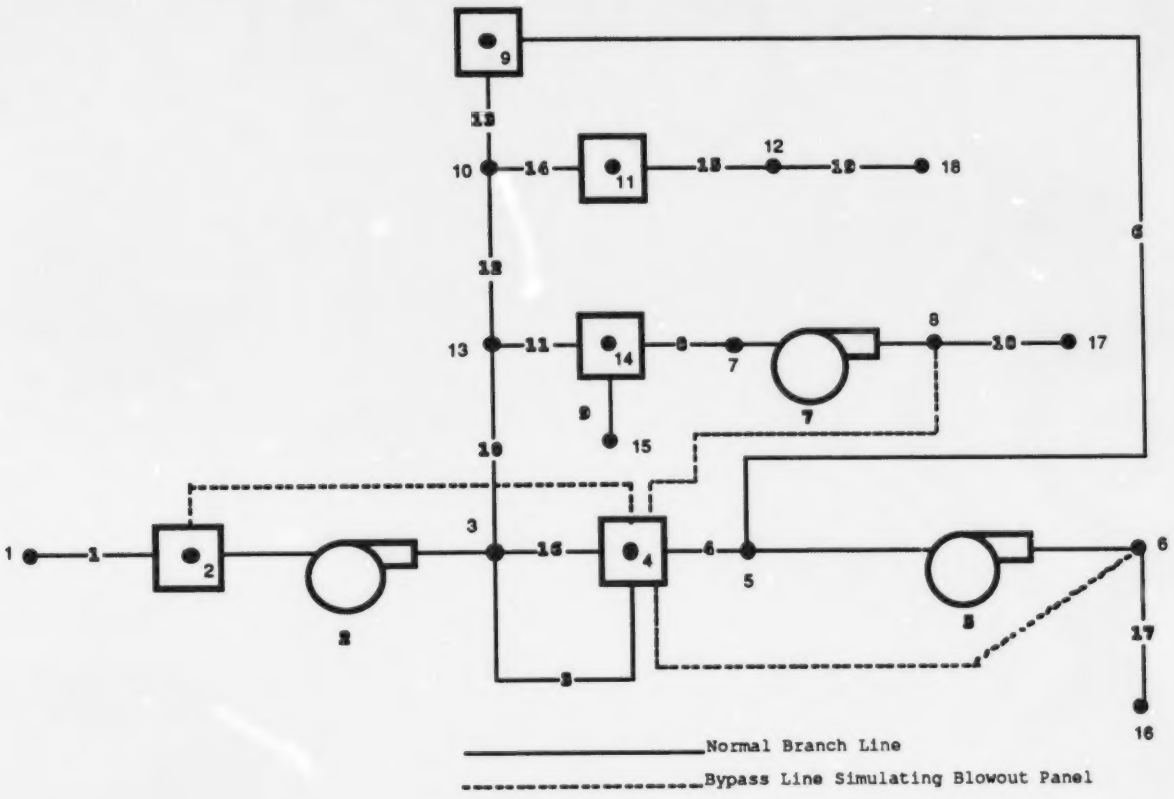


Figure 42
EPG Schematic Detailing Louvres and Showing Blowout Panel Bypass Routes

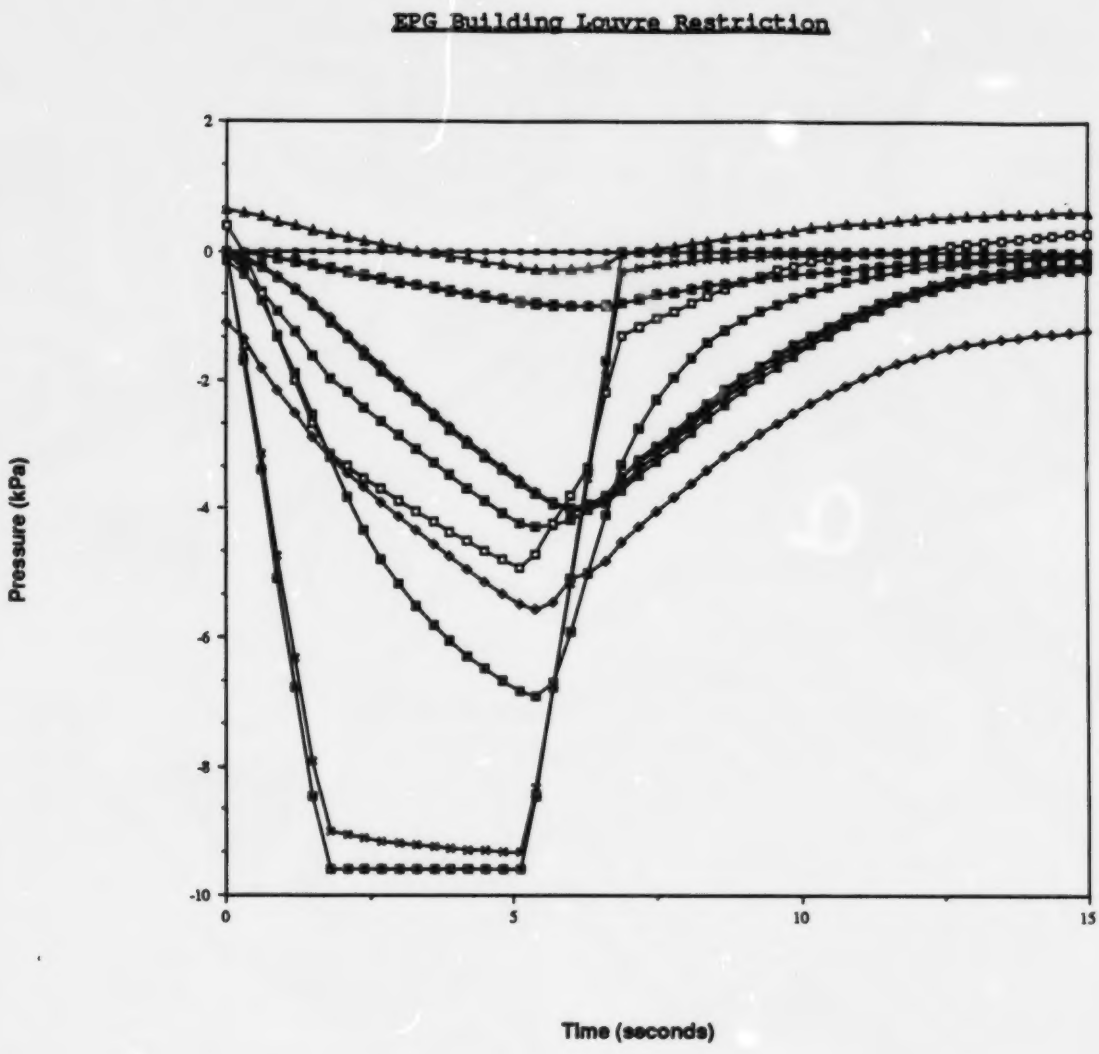


Figure 43
EPG Pressure Profiles With R*10 Louvre Resistance Added

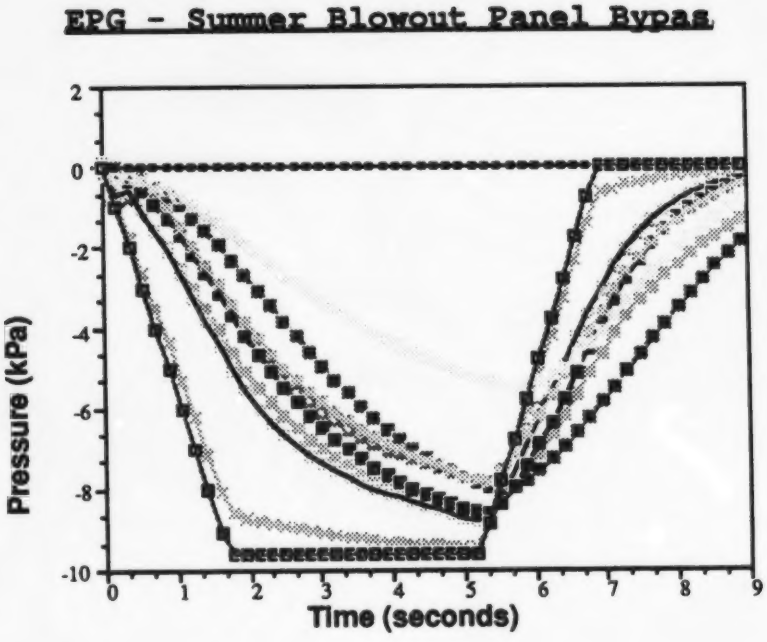


Figure 44
Pressure Distribution in EPG Building With Blowout Panels to Fan Room